FISCAL YEAR 1992 DEPARTMENT OF ENERGY AUTHORIZATION

(Fusion Energy)

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY HOUSE OF REPRESENTATIVES

ONE HUNDRED SECOND CONGRESS

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CONTENTS

March 13, 1991:

Page

Opening statements by:

Hon. Marilyn Lloyd, chairman, Subcommittee on Energy 1

Hon. George E. Brown, Jr., chairman, Committee on Science, Space, and Technology 2

Hon. Steven H. Schiff 2

WITNESSES

Dr. James F. Decker, director, Office of Energy Research; accompanied by Dr. N. Anne Davies, Office of Fusion Energy, U.S. Department of Energy, Washington, DC 3

PANEL 1

Dr. Ronald C. Davidson, director, Plasma Physics Laboratory Princeton, NJ 22

Dr. Ronald R. Parker, director, Fusion Laboratory, Massachusetts Institute of Technology, Cambridge, MA 45

Dr. Roger O. Bangerter, group leader, Heavy Ion Fusion Accelerator Research Division, Lawrence Berkeley Laboratory, Berkeley, CA 55

Dr. David O. Overskei, senior vice president, Fusion Division, GA Technologies, Inc., San Diego, CA 63

PANEL 2

Dr. Harold K. Forsen, vice president, Research and Development, Bechtel Power Corporation, San Francisco, CA 78

Dr. Stephen O. Dean, president, Fusion Power Associates, Gaithersburg, MD 82

Dr. Alexander J. Glass, associate director for programs, Lawrence Livermore National Laboratory, Livermore, CA 87

APPENDIX I: OPENING STATEMENTS FOR THE RECORD

Hon. Sid Morrison, ranking Republican member, Subcommittee on Energy 107

Hon. Jerry F. Costello 108

APPENDIX II: ADDITIONAL MATERIAL FOR THE RECORD

Dr. John Sheffield, Fusion Energy Program, Oak Ridge National Laboratory, Oak Ridge, TN 109

Dr. Rulon K. Linford, Los Alamos National Laboratory, Los Alamos, NM 113

GA paper entitled: *Technology Derived from the Fusion Research Program* 116

Dr. William R. Ellis, Ebasco Services, Incorporated, New York, NY 124

APPENDIX III: QUESTIONS AND ANSWERS FOR THE RECORD

Dr. James F. Decker, Director of the Office of Energy Research, Department of Energy 129

Dr. Ronald C. Davidson, director, Plasma Physics Laboratory, Princeton, NJ 133

Page

March 13, 1991—Continued

Dr. Ronald R. Parker, director, Fusion Laboratory, Massachusetts Institute of Technology, Cambridge, MA 137

Dr. Stephen O. Dean, president, Fusion Power Associates, Gaithersburg, MD 139

Dr. Alexander J. Glass, associate director for programs, Lawrence Livermore National Laboratory, Livermore, CA 141

Dr. Harold K. Forsen, vice president, Research and Development, Bechtel Power Corporation, San Francisco, CA 143

Dr. Roger O. Bangerter, group leader, Heavy Ion Fusion Accelerator Research Division, Lawrence Berkeley Laboratory, Berkeley, CA 153

Dr. David O. Overskei, senior vice president, Fusion Division, GA Technologies, Inc., San Diego, CA 155

1992 DEPARTMENT OF ENERGY AUTHORIZATION

WEDNESDAY, MARCH 13, 1991

U.S. HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
SUBCOMMITTEE ON ENERGY,
Washington, DC.

The subcommittee met, pursuant to notice, at 9 a.m., in room 2325, Rayburn House Office Building, Hon. Marilyn Lloyd (chairman of the subcommittee) presiding.

OPENING STATEMENT OF HON. MARILYN LLOYD, CHAIRPERSON, SUBCOMMITTEE ON ENERGY

Mrs. LLOYD. Good morning, ladies and gentlemen. And good morning, Vice-Chairman and members and staff.

Dr. Decker and Dr. Davies, it's certainly nice to have you with us today, and distinguished ladies and gentlemen in our audience. This is a very important hearing this morning on the Department of Energy's budget request for fiscal year 1992 Fusion Energy Program.

We're now in a time in history when truly there is a window of opportunity to move forward, and rather sizably, on the domestic energy front. It's an occasion we've all been looking forward to. I'm going to keep my remarks rather short because I do think we're going to have a very lively interchange with our distinguished witnesses who are with us today.

In contrast to a somewhat discordant picture about a year and a half ago, there's now a growing sense of progress and enthusiasm in this program. And the report of the Fusion Advisory Committee has helped to give it a unified focus for the program. And I know that many of you here today were very active in this very important FPAC deliberation.

We also see evidence that support is building in the Department of Energy. And certainly last, but not least of all, I'm very happy that our Full Committee Chairman, Congressman Brown, is very enthusiastic about our program, and I'm very delighted about his leadership. And under his leadership, I do see a great deal of progress for this committee to share, and I'm very grateful to you, Chairman Brown.

All these forces speak well for the future of the Fusion Program. The budget request is an increase in funding for the Fusion Energy Program compared to last year's level. I do want to emphasize to the witnesses today that our hearing is intended to provide a base of information for the subcommittee to provide for a multi-year authorization.

In this context, we're going to see how the proposed fiscal year 1992 program ties into the longer term objectives. We're going to be looking beyond fiscal year 1992. Our focus will be on the underlying strategy for the fusion energy programs. This includes the goals, the milestones, and the key decisions over the next several years. In short, we want to know how today's program is going to fit into our long-term strategy.

I do welcome all of you here today. I would at this time like to recognize Chairman Brown.

OPENING STATEMENT OF HON. GEORGE E. BROWN, JR., CHAIRMAN, COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

Mr. BROWN. Thank you very much. I do not intend to make a statement, but I do want to compliment you on your continuing efforts in support of fusion. As a matter more of nostalgia than anything else, I have been interested in fusion for about a quarter of a century. And I am very much interested in seeing us move to the point where we are seeing the possibility of true commercial power, which I see as emerging from our success with the ITER Project, and I'm looking forward to having the committee move very aggressively in this area. And I hope you will continue with your strong support, also.

Mrs. LLOYD. Thank you very much, Mr. Chairman.

Mr. Schiff?

OPENING STATEMENT OF HON. STEVEN H. SCHIFF, MEMBER, SUBCOMMITTEE ON ENERGY

Mr. SCHIFF. Thank you, Madam Chairman. Very briefly I want to say first that Congressman Sid Morrison, our ranking member, has a conflict in scheduling. He'll be along in a few minutes, and I'm temporarily taking his place.

Second of all, though, I want to say that in my second term in Congress I went out of my way to seek reappointment to the Science, Space, and Technology Committee, and specifically to your Subcommittee on Energy as my first choice. And I did so because there's been a recognition on this Committee, and particularly with you as Chairperson of this Subcommittee, that the science issues, in particular the energy issues, have no side of the aisle.

Under Chairman Roe, under Chairman Brown, under yourself as the Chairperson of this committee, you've welcomed the ideas and contributions of all the members because we all have the same goals. We all seek the same advances in our country, regardless of how we might agree or disagree on other political issues in other places. So it was really a pleasure and a privilege for me to serve last term, and the same pleasure and privilege exists today.

Mrs. LLOYD. Thank you, Mr. Schiff. The Chair welcomes all good words. That's the way to start a day. And I do have unanimous consent that today's hearing is to be covered by the media.

And our first witness for the morning is Dr. James Decker, Director of the Office of Energy Research at the Department of Energy, and he's accompanied by Dr. Anne Davies, she's the Acting Associate Director for the Office of Fusion Energy. Please proceed.

STATEMENT OF DR. JAMES F. DECKER, DIRECTOR, OFFICE OF ENERGY RESEARCH, DEPARTMENT OF ENERGY, ACCOMPANIED BY DR. N. ANNE DAVIES, ACTING ASSOCIATE DIRECTOR, OFFICE OF FUSION ENERGY

Dr. DECKER. Thank you, Madam Chairman. I'm pleased to be here today to discuss the fiscal year 1992 budget request for the Department of Energy's Fusion Energy Research Program.

Fusion energy promises an essentially limitless source of energy, with significant safety and environmental advantages for the generation of electricity. A fusion power plant cannot have a runaway nuclear accident, would not have the emissions that could contribute to global warming or acid rain, and with the development of low activation materials, fusion would significantly reduce the problems associated with a generation in disposal of radioactive waste.

This morning I want to highlight some of the technical accomplishments of the fusion program. Tokamak plasma parameters have increased by over a factor of a million during the last 15 years. Only an additional factor of about seven is required for a fusion reactor. A ratio of plasma pressure to confining magnetic field pressure has been achieved which is considered adequate for a fusion reactor. Only a few years ago there was some significant doubt that sufficient plasma pressure could be confined in a tokamak to make an economical reactor.

Early control techniques have been developed that have significantly increased performance of TFTR and Doublet III. Scale model superconducting magnets with fields in range required for a fusion reactor have been successfully tested. Over 10 billion curies of tritium have been safely handled using techniques developed at the Tritium Test Assembly, located at the Los Alamos National Laboratory. And the ITER Conceptual Design Activity was successfully completed in December 1990.

Although steady technical progress has been made in recent years, achieving fusion energy is still a difficult technical challenge that will require a long-term R&D commitment over a time frame of decades.

During the past year the Department's fusion programs were thoroughly reviewed by the Fusion Policy Advisory Committee that was chartered by Secretary Watkins. The Fusion Policy Advisory Committee concluded that the U.S. should initiate a goal-oriented fusion energy development program, and that the program is technically ready to proceed with the next major step. Secretary Watkins accepted the committee's recommendations, and from them developed the Department's new fusion policy as described in the National Energy Strategy and our fiscal year 1992 budget submission.

The Department's fusion policy is to develop both the magnetic and inertial fusion energy approaches concurrently, and, for the first time, put the focus on development. Long-term goals are to have an operating demonstration power plant by about 2025 and an operating commercial power plant by about the year 2040.

However, because of the Congressional budget cut in fiscal year 1991 and the severe budget constraints for the foreseeable future,

we're not able to implement all of the Fusion Policy Advisory Committee's recommendations. We have had to eliminate our research on magnetic fusion approaches and alternatives to the tokamak. Therefore our magnetic confinement fusion research and development is now focused solely on the tokamak. Similarly, in our program to develop energy applications of inertial confinement, project constraints limit us to pursuit of the heavy ion driver option.

There are two key facilities central to the Magnetic Fusion Program: The International Thermonuclear Experimental Reactor, which goes by the acronym ITER; and the Burning Plasma Experiment.

ITER is a joint effort of Japan, the European Community, the Soviet Union and the United States. The mission of ITER is to develop the technology needed for a fusion reactor. The ITER Conceptual Design Activity was initiated in May of 1988, and completed in December of 1990. The first round of negotiations with our international partners to initiate the next phase of ITER, the Engineering Design Activity, was held in Vienna in February.

The Engineering Design Activity would last six years, and includes both engineering design and research and development. The total estimated cost of the ITER Engineering Design Activity would be about $1 billion—and that's in 1989 dollars—for all parties, or about $300 million in as spent dollars for the United States.

Good progress was made on the text of an agreement during the recent negotiations. A major unresolved issue is the site for the Joint Central Team. The U.S. has proposed a site in San Diego for our candidate for the location of the Central Team. The European community and Japan have also made site proposals. The decision on the site will be made at some future negotiating session.

The other key facility central to our new fusion policy is a Burning Plasma Experiment. It will be the cornerstone of the U.S. domestic Magnetic Fusion Program. It will make important contributions to ITER. Its mission is to determine the physics behavior of self-heated fusion plasmas and demonstrate the production of significant amounts of fusion power—over 100 megawatts. Design, R&D, and prototype fabrication for the Burning Plasma Experiment will continue in fiscal year 1992.

The third major thrust in the Magnetic Fusion Energy Program this year is preparation for deuterium-tritium experiments in TFTR to begin in 1993.

In inertial fusion energy we will continue our reactor studies begun last year, and we will begin the next phase of heavy ion accelerator research and development. The heavy ion work, which has been conducted in the Office of Basic Energy Sciences, will be moved to the Office of Fusion Energy in order to consolidate management of our Fusion Energy Program. Our inertial fusion energy effort will continue to depend on the target physics work that is conducted by Defense Programs in the Department.

I wanted to take this opportunity to thank the Committee for their support of the fiscal year 1991 reprogramming action. Without the reprogramming, it would have been nearly impossible to move forward toward the Fusion Energy Program recommended by the Fusion Policy Advisory Committee.

This concludes my introductory remarks, and I'd be pleased to answer any questions you may have.

[The prepared statement of Dr. Decker follows:]

Statement of James F. Decker

Acting Director

Office of Energy Research

Department of Energy

before the

Subcommittee on Energy

of the

Science, Space, and Technology Committee

U. S. House of Representatives

March 13, 1991

Madam Chairman and members of the Subcommittee:

Fusion continues to offer the promise of a safe, environmentally benign, secure, and affordable source of energy. A fusion power plant would contain only a small inventory of fuel, thus eliminating the possibility of a severe, uncontrolled reaction. Operation of a fusion reactor would not contribute to acid rain or global warming; and it is well established that the deuterium fuel required for fusion is plentiful and could be readily obtained from sea water. Manufacture of tritium, which is also required in a fusion reactor, could be accomplished at the reactor site, thus reducing both the risk and cost involved in transporting the radioactive fuel to the site.

The Department has recently concluded an in-depth review of the fusion program by the Secretary's Fusion Policy Advisory Committee (FPAC) to determine an appropriate, practical, and enduring fusion policy. As a result of that review, the Department has established a policy to proceed with a goal-oriented program for the development of fusion energy. Although scientific investigation of the fusion process will continue to be an integral part of the program, the primary long-term goals of this policy are to have an operating demonstration power plant by about 2025 and an operating commercial power plant by about 2040. The Department's new fusion policy supports the National Energy Strategy goals aimed at strengthening the foundations of future U.S. energy security, economic growth, and environmental progress.

The strategy for obtaining the Fusion program's long-term goals is to support two separate and distinct approaches to fusion energy development as recommended by FPAC: magnetic fusion energy and inertial fusion energy. In the magnetic approach to fusion energy, the fusion fuel--a mixture of

deuterium and tritium--is heated to temperatures hotter than those found in the sun. This produces an ionized gas called a plasma. The normal tendency of such a super hot plasma would be to expand and cool. In a magnetic fusion device, a strong magnetic field is used to prevent the plasma from expanding so that the combined conditions of high temperature and fuel density necessary to achieve a fusion reaction can be obtained.

In the inertial confinement approach to fusion, a small pellet of fuel is rapidly compressed and heated by bombarding it with light from a laser or charged particles from an accelerator. The laser or accelerator used is called the inertial fusion energy (IFE) driver. The compression and heating of the IFE fuel pellet takes place so quickly that the fuel's own inertia keeps it confined while there is a miniature thermonuclear explosion that produces a pulse of energy.

The pursuit of both the magnetic and inertial fusion options will reduce the technological risk associated with the difficult task of developing fusion energy. Another important element in carrying out this strategy is to take full advantage of international collaboration while maintaining a sound domestic program. Increasing involvement of industry as fusion becomes an energy development program will also be pursued.

To pursue the energy applications of inertial fusion, the Secretary has established an IFE subprogram within the Fusion Energy program. In addition, the new IFE program will require continued development of the knowledge being produced in Defense Program's Inertial Confinement Fusion (ICF) activity.

Based on the advice of the FPAC, the Department is proposing to transfer the Heavy Ion Fusion Accelerator Research previously funded in the Office of Energy Research's (ER) Basic Energy Sciences program to this new IFE subprogram in FY 1992. The heavy ion beam is considered the best driver for IFE applications. A review of security classification of ICF information is underway. Reduced classification, if appropriate, could allow enhanced international collaboration in the energy applications of ICF results. Collaboration on driver development and reactor technology will be sought in any event.

The overall approach for developing both magnetic and inertial fusion is to gain scientific understanding of the processes involved in burning and ignited plasmas and to use this understanding to develop fusion technology in an engineering test facility. (A burning plasma produces energy in excess of what is required to sustain the fusion reaction. An ignited plasma is a self-sustaining fusion reaction that no longer requires external heating.) The final step toward commercialization would be construction of a demonstration power plant. The overall program aimed at achieving these goals must include the study and development of the most effective confinement systems, materials, and technology to ensure the eventual economic success of fusion.

The economics of a fusion reactor depend on several unresolved technical issues and are hard to determine with certainty at this time. A vigorous development program is required over the next three decades to demonstrate technical feasibility and accurately determine the economics of fusion energy.

4

Key technology issues that would enhance magnetic fusion's economic and environmental characteristics include: (1) the blanket, which is the area of the reactor outside of the plasma chamber wall that is used to convert neutrons to heat and produce tritium; (2) heating and fueling systems; (3) large high field superconducting magnets; and (4) materials development. To produce additional tritium to be used as fuel, a fusion reactor will include a breeding blanket that contains lithium. The lithium in the blanket will be converted to tritium by neutrons that are produced by the fusion reaction. The blanket would also have a role in energy extraction and radiation shielding. In addition to developing the required blanket and plasma heating and fueling technology for a fusion reactor, large, high-field superconducting magnets need to be developed that have the size, field, current and reliability required for a reactor-sized device. Another key requirement is the development of low activation materials, which develop minimum radioactivity when exposed to the neutron flux emanating from a fusion reactor. These materials could greatly enhance fusion's environmental and safety characteristics.

A broad international consensus now exists on how ignition and burn of a magnetically confined fusion plasma can be achieved, and significant progress has been made toward this goal. To date, the most effective way to magnetically confine a plasma is in a toroidal, or doughnut-shaped, device, called a tokamak. Recent results indicate that the Tokamak Fusion Test Reactor (TFTR) in the U.S. and the Joint European Torus in the European Community are very close to breakeven plasma conditions. Breakeven is

achieved when the energy produced by the fuel would equal the energy applied to heat the fuel.

There have been numerous physics and technology accomplishments in the magnetic fusion energy program, including:

(1) improvement in tokamak performance, in terms of fusion power production, of more than a factor of a million over the past 15 years, with only an additional factor of about 7 required, to reach ignition;

(2) achievement of an experimental ratio of the plasma pressure to the pressure of the confining magnetic fields of about 11 percent in the Doublet III-D device, results that are considered adequate for an economic reactor;

(3) identification of means to produce the confinement modes required for burning plasmas;

(4) enhancement of the prospects for steady-state current drive in a tokamak reactor through use of neutral beams on Doublet III-D and TFTR and confirmation of a theoretically predicted "bootstrap" current, both of which are important for economical steady-state tokamak operation;

(5) production of plasma conditions near a regime of higher plasma pressure with lower external magnetic fields, that could dramatically improve the efficiency of a tokamak reactor;

(6) development of radiofrequency heating at Oak Ridge National Laboratory and in industry allowing high-power, localized heating of a tokamak, which supports the design of the Burning Plasma Experiment

and International Thermonuclear Experimental Reactor devices, both of which are discussed later in this statement;

(7) development of techniques and technology that have reduced plasma impurity content and increased the performance of TFTR and Doublet III-D;

(8) successful tests of scale-model superconducting coils with magnetic field strength approximately in the range required for a fusion reactor;

(9) demonstration of safe handling techniques for fusion fuels (deuterium and tritium) at the Tritium Systems Test Assembly where the processing system has safely handled over 10 billion curies of tritium; and

(10) completion of the International Thermonuclear Experimental Reactor Conceptual Design Activities, which have been a model of successful international collaboration on a large scientific project.

FY 1992 FUSION ENERGY BUDGET REQUEST

The FY 1992 budget request for Fusion Energy is $337.1 million. This includes $321.6 million for Operating Expenses, $11.0 million for Capital Equipment, and $4.5 million for Construction (Table 1).

As just mentioned, the magnetic fusion effort has been focused on the tokamak and on an integrated international approach to demonstrate the scientific and technological feasibility of fusion power. A conceptual design study for the International Thermonuclear Experimental Reactor (ITER) was initiated in FY

Table 1
Energy Supply R&D
Fusion Energy
Budget Authority
($ in millions)

	FY 1990	FY 1991[a/]	FY 1992 Request
Operating Expenses			
Confinement Systems	$ 160.2	$ 150.9	$ 183.3
Applied Plasma Physics	71.6	62.9	61.7
Development and Technology	46.3	46.6	56.7
Planning and Projects	.7	4.1	4.2
Inertial Fusion Energy	1.1	1.6	8.2
Program Direction	4.9	5.5	7.5
Subtotal	$ 284.8	$ 271.6	$ 321.6
Capital Equipment	13.3	10.4	11.0
Construction			
General Plant Projects (GPE-900)	7.7	2.1	1.9
Confinement Physics Research Facility (89-R-800)	10.9	5.5	0
Fire and Safety Project, PPL (92-E-340)	0	0	2.6
Subtotal	18.6	7.6	4.5
Total Fusion Energy	$ 316.7	$ 289.6	$ 337.1

[a/] Assumes proposed reprogramming request of $16.0 million is approved.

1988 as a joint four party effort involving the U.S., the European Community, Japan, and the U.S.S.R. The effort was carried out under the auspices of the International Atomic Energy Agency. The objective of ITER is to demonstrate the scientific and technological feasibility of magnetic fusion power for peaceful purposes. ITER will provide a focus for the world-wide effort on the tokamak concept. The U.S. has decided to enter negotiations to participate as an equal partner in the ITER Engineering Design Activities. A decision on future ITER construction activities, including U.S. participation, will be made sometime after 1997. ITER will provide: (1) the physics data base needed for a demonstration tokamak power reactor, (2) many of the reactor technologies needed for fusion power, and (3) a test bed for high heat flux and nuclear components. The FY 1992 budget request for ITER is intended to provide for the conduct of engineering design, supporting R&D and development of component models which could be scaled up to full size.

To contribute to the success of ITER and maintain a strong domestic program, experiments using deuterium and tritium fuel will be carried out in TFTR in mid-1993 and will provide R&D in support of the engineering design of a Burning Plasma Experiment (BPX). The purpose of the BPX would be to investigate the physics of self-heated plasmas and to demonstrate the production of 100-500 megawatts of fusion power. In the process, the BPX would provide information on the confinement physics, operational limits, and alpha particle physics of self-heated plasmas. In addition, it would demonstrate many of the heating, fueling, and plasma handling techniques necessary to produce reactor-level fusion plasmas. The BPX, which evolved from the Compact Ignition Tokamak (CIT), more appropriately addresses the

strategic physics required for a fusion energy program and incorporates a more conservative approach to the engineering design than the CIT. The FY 1992 budget for the Burning Plasma Experiment project provides for an expansion of the FY 1991 effort on the preliminary design as well as a more intensive program of R&D and prototype development. A decision on whether to proceed with construction will be made within the next budget cycle. The Department is actively exploring opportunities for international collaboration.

Other tokamak experiments, including the Princeton Beta Experiment (PBX), will be focused to support these major experiments. The PBX will be restarted in FY 1992 to investigate the possibility of making more efficient use of magnetic fields through shaping of the plasma. Technology development will be focused to validate ITER design and to support TFTR, Doublet III-D and BPX. Due to budget reductions beginning in FY 1991, we will not be able to continue U.S. development of magnetic confinement concept alternatives to the tokamak, including work on reversed field pinches, stellarators, and compact toroids. However, we will keep abreast of the achievements of our international partners in this area.

In keeping with the above, the FY 1992 Operating Expenses request of $321.6 million provides for R&D, prototype fabrication, and design for the BPX project, preparation of the TFTR device for experiments with deuterium and tritium fuel in late 1993, and experimental physics support for BPX and ITER. An increase in ITER project support is also included to initiate engineering design tasks and for those R&D tasks that require the longest lead time and are the most critical to the success of ITER, such as superconducting magnets,

ceramic blanket model fabrication methods, high heat flux components, and design of electrostatic accelerators for neutral beam heating systems.

The FY 1992 Operating request also provides $8.2 million for initiation of an Inertial Fusion Energy program focused on one driver concept and associated technology development. Recent successes in inertial confinement fusion tests have led to confidence that net energy release in the laboratory is possible through implosion, ignition, and burn of microcapsules of deuterium-tritium fuel. This program will rely on continuing development of target physics and ignition characteristics funded under Defense Programs. The heavy ion driver, successfully conceived through Defense Programs and ER's Basic Energy Sciences activities, will be tested at increasing levels of intensity. Technology R&D will be based on reactor studies and will rely on progress within the world-wide magnetic fusion program for common elements such as low activation materials needed for fusion containment and for breeding blankets. Where possible, international cooperation will be pursued to speed overall progress in IFE.

The Operating Expenses request also provides $7.5 million in Program Direction funds for the salaries, benefits, travel and other expenses associated with 77 full-time equivalent employees required to administer the Fusion Energy program.

The FY 1992 Capital Equipment request of $11.0 million provides essential hardware to support the overall program. This equipment includes diagnostic

and computer equipment, power supplies, and other components for experimental facilities.

The FY 1992 Construction request of $4.5 million provides $1.9 million for General Plant Projects. These projects provide for the continuing minor alterations and modifications necessary to meet health, safety, and programmatic requirements and to protect the Government's investment in its facilities. The remaining $2.6 million is for initiating the Fire and Safety Protection Improvements construction project at Princeton Plasma Physics Laboratory.

That concludes my statement. I would be happy to answer questions.

Mrs. LLOYD. Thank you very much.

Mr. Brown?

Mr. BROWN. Let me ask a parochial question, if I may, with regards to our efforts to negotiate the San Diego site for the ITER. Do either of you care to offer an evaluation of what the future holds with respect to our negotiations? And, hopefully, can you suggest ways that might make our position a little bit stronger? Any strategy or tactics that we might assist in that will be helpful?

Dr. DECKER. Mr. Brown, the negotiations at the present time are really deadlocked. All three countries that have proposed sites feel very strongly about the need to have that particular activity in their country. We continue to look for innovative ways to come out with some sort of an agreement that meets the needs of all the parties. But it clearly is going to be difficult to do that. I think each party feels to some extent that the political support in their country for fusion research in general depends to some significant amount on whether or not this activity is located in their country. And that's one of the great difficulties.

Mr. BROWN. You didn't go far enough.

Dr. DECKER. Okay.

Mr. BROWN. I think understanding all these things, which I'm absolutely sure you're correct on, it may be that we will have to offer—and this would apply to the other countries, as well—something beyond the strict merits of the site, shall we say; maybe some sweetener of one sort or another, or some collateral or kinds of agreement. And I'm, of course, not suggesting anything here that would go beyond the bounds of propriety, but negotiation frequently is successful when you think of imaginative ways to supplement the offers that any of the parties may be making. I won't belabor this, it may well be that this is a very sensitive subject that is not one suitable for a hearing process. But if either you or Dr. Davies have any suggestions at all, I assure you that the committee would welcome them either publicly or privately.

Dr. DECKER. Mr. Brown, it is a sensitive subject to be sure. I think that we have, first of all, a very attractive proposal on the table from San Diego. It really is an excellent proposal. The people in San Diego who have worked on this have done an excellent job. We have done a lot to provide incentives for the other parties to want to go to San Diego for this activity. But I think that what we really have to find is some way to, as I said earlier, provide each party with something out of this negotiation that they can go home with and be proud of for their political leaders.

Mr. BROWN. Well, I think that's right, and that's the direction that I was thinking of. I wouldn't go so far as to say that our own future support of fusion depends upon our site being selected, but I think I can tell you that there's a certain amount of national pride involved in having the site located here. That it is likely to contribute to a greater interest and understanding of the program, and hopefully that would result in more support of funding in the future. But as far as I'm personally concerned, the program will be supported regardless of whether it's located here or in some other country. If we don't get the Engineering Design Activity, then we can increase our efforts to get the site for the plant itself when it's being built. But we're very much interested in what you're doing.

Dr. DECKER. Thank you.

Mrs. LLOYD. Thank you very much, Mr. Brown.

Mr. Schiff?

Mr. SCHIFF. Dr. Decker, can you give me an overall view? We're talking about fusion energy, but we still don't have ignition in the laboratory, as I understand it, we haven't reached that point yet. This is an unknown, of course, but is there any reasonable prospect to know when we might actually see a schedule of ignition and then leading to an actual commercial reactor of some kind?

Dr. DECKER. Mr. Schiff, we do not have a fusion device in the world today that is capable of reaching the ignition goal. And that is why we are looking at the possibility of building this Burning Plasma Experiment, to get at the physics issues associated with a strong self-heating in the plasma and eventually ignition. But that we feel is a very necessary side.

Mr. SCHIFF. I guess I just asked you how high is up, really. It really can't be answered. Let me then ask a theoretical question. In theory, as the scientists now plan fusion research and an eventual fusion reactor, would we foresee an environmental threat from a fusion reactor as we've seen from certain nuclear reactors, such as Chernobyl and so forth? Is that anticipated to be a problem in and of itself, or would fusion be a means of eliminating those kinds of threats?

Dr. DECKER. Mr. Schiff, fusion does have significant advantages in these particular areas. There is not a danger of a nuclear runaway in a fusion reactor. There is only a very small amount of fuel in the fusion reactor itself.

Second, almost anything that you can imagine that would go wrong—a failed magnet, or a failure in the vacuum chamber, whatever—just automatically stops the fusion reaction from occurring. I think from that point of view fusion reactors will offer some rather significant advantages.

In the area of radioactive wastes, yes, there are radioactive wastes in fusion reactors. They're not inherent in the fusion process itself, but the neutrons produced by the fusion reactions will activate structural materials in the reactor. The key here is to try to develop low-activation materials that will greatly reduce the radioactivity in the structural material, and I think that looks very promising.

And I think there have been comparisons made with fission reactors. And if you look a year after the shutdown of a fusion reactor versus a fission reactor, the levels of radioactivity in the fusion reactor are very much lower. And if you look 10 years later, it's much lower and so forth. And that's because in the fusion reactor, one can avoid these very long-lived radioactive materials.

Mr. SCHIFF. May I have 1 minute, Madam Chair? Thank you very much Dr. Decker, I appreciate it.

Mrs. LLOYD. Dr. Decker, this certainly was an impressive testimony. Last evening when I was reading your testimony, and we're looking to 2025 and 2040 for commercialization, I thought of something that a group of Marines said to me when I was in the Persian Gulf last December. They said, "Congresswoman, we know why we're over here, we're over here for our children." And I can think of no greater legacy that we're leaving to our children and our

grandchildren than the prospect of fusion energy. So it's really most impressive. And then your list of accomplishments also certainly speaks well for your efforts.

Dr. Davies, I understand that you've just returned from the Soviet Union. I'm sure you had a very enlightening trip. What is the latest international news on ITER from that front? What can we really expect in dollars and cooperative efforts? And, more specifically, what do we want?

Dr. DAVIES. This was a very informal meeting. I met with my counterparts from Japan, and the European Community, and the Soviet Union. We met in Moscow because of all of the schedules, it was the only time and the only place all four of us could meet. But this was an attempt to try to explore ideas to see if there was any way around this impasse over site. And there were some ideas that I expressed that we think we want to do some homework on to see whether we could come up with anything that the negotiators could work with later. But that was the purpose was to see if anybody had any idea about how to get around——

Mrs. LLOYD. Did you reach any conclusions?

Dr. DAVIES. No, we did not. We did not. Several of us had suggestions to talk about. And we asked people then to do homework for us and for the negotiators over the next two to four weeks.

Mrs. LLOYD. In looking at the program, I'm excited about the D–T experiment at Princeton. I understand it's about two, two-and-a-half years away, Dr. Decker. And because of our budget constraints, we're going to look toward the major concepts and rely more on international cooperation for the more alternate concepts. And I think this means we're going to mothball some of our facilities. Do you think that the real risks are on the downside or the upside to this? I'd like for you to really elaborate the fact that we are going to mothball some major facilities, Doctor Decker.

Dr. DECKER. It was a very difficult decision to cutback our work on alternate concepts in the program. It is a step that does increase our technical risk to some extent. But under the budget circumstance, we really felt that there really wasn't any choice at the time.

We are trying our best to utilize the teams of people who have worked on those experiments over the years. We will try to use them primarily on tokamak experiments where we can. In some instances, at least in the case of the ATF at Oak Ridge, that device will be mothballed. We might come back to it at a later time if technically it looks like there is really important information that we could get from that device, and assuming we have the funds to do it. So we will retain that capability, at least in that case.

Mrs. LLOYD. Well, now, what sort of additional funding would it take to keep from mothballing some facilities that have been pretty important to us? What are we looking at?

Dr. DECKER. One of the reasons why we made the decision to drop the alternate concepts was that looking forward to the future, it looked like it was going to take an additional $40–$50 million a year to really pursue those programs in a reasonable way. We had not been pursuing them with adequate funding for a number of years. I don't think that there was any of those programs that were really operating in an optimal way.

Mrs. LLOYD. Well, they've been on roller coasters for quite some time now.

Dr. DECKER. That's right.

Mrs. LLOYD. Well, do you feel that at this time instead of the roller coaster that we really have a good, straight ahead vision that we can predict where we're going with your new concept?

Dr. DECKER. We believe so. We have now narrowed the program to the point where we really are down to a core effort. We could not stand to reduce the program below where we are and, at least in my view, continue an active participation in even the ITER Project.

Mrs. LLOYD. Well, we want to move ahead with predictability in our efforts as we look toward multi-year funding. I think it's not only important for our program, I think it's important if we're going to have an international collaboration that there can be a degree of dependability. If we say we're going to make a contribution, that they can count on it being there and not subject to OMB cuts from year to year. I think that's just one of the most significant things that we can do in this Congress.

Now, it's my understanding that we are going to do the work on the D–T Experiment and engineering work for BPX as our contribution. Have we really outlined what the challenges, the expectations will be for all of our international work, our cooperative efforts?

Dr. DECKER. There will be additional work that we will have to do beyond D–T in TFTR.

Mrs. LLOYD. I realize that, but that would be our major contributions.

Dr. DECKER. Those are two major programs that will contribute, of course, but there is additional research and development and design work, of course, that we will do. And that is part of our budget request.

As far as additional international activities, we really need, I think, to work closely with our major international partners to better layout an international fusion program.

There are clearly one or two other significant devices that will be needed in the longer term to develop fusion energy, in addition to ITER. For example, I think everyone agrees that at some point there needs to be a 14 MeV neutron source to do materials research for a fusion power plant.

Mrs. LLOYD. One final question. I know we have $8 million in the Inertial Fusion Research Program. Do you think that this is really going to be sufficient to take care of the laser, the accelerator driver?

Dr. DECKER. We have to remember that there is about $180 million of inertial confinement research that's being supported over in the Defense Program. And that work is concentrating on the really key problem in target physics. What we are doing on the civilian side is to work on reactor studies for inertial confinement on fusion energy reactors and, secondly, to work on a heavy ion driver, which is considered the most promising driver for a commercial energy application. And we believe with these budget constraints, that the amount of money that we have budgeted is adequate to do that. We are certainly not able to carry out all of the Fusion Policy Advisory

Committee recommendations in inertial confinement, no more than we could on the magnetic fusion side.

Mrs. LLOYD. We appreciate your testimony. We hope that you will keep the committee informed of your progress and activities, not just at budget request times, but I hope that we can continue to have conversations to review the progress through out the year because I do think that this is a very significant year for your program.

Again, I want to congratulate both of you for a job well done.

Mr. Cramer?

Mr. CRAMER. Madam Chairman, I have no questions.

Mrs. LLOYD. Thank you very much. Mr. Brown, do you have any questions?

Mr. BROWN. No, thank you.

Mrs. LLOYD. I think that you're through, then.

Dr. DECKER. Okay. Thank you very much.

Mrs. LLOYD. Thank you.

We're going to move now to our first panel of witnesses. The first witness is Dr. Ronald Davidson, he's Director of the Plasma Physics Laboratory; Dr. Ron Parker is Director of the Fusion Laboratory at MIT; Dr. Roger Bangerter is Group Leader of the Heavy Ion Fusion Accelerator located at Lawrence Berkeley Laboratory; and Dr. David Overskei is Senior Vice President of Fusion Division at GA Technologies. We're looking forward to you being with us and hearing all the good things you've been doing in the past year.

And, Dr. Davidson, please proceed. And I'd like to tell all of you if you'd like to summarize your testimony, that your entire statement will be made a part of record. And I'd also like to tell all the witnesses today that as we look over the testimony there are going to be questions that we would feel like we'd like to have more specific answers, so I'd like to warn all the witnesses that we will be submitting questions in writing that we'd like you to answer for the record. So you all have been warned.

Please proceed.

STATEMENT OF DR. RONALD C. DAVIDSON, DIRECTOR, PRINCETON PLASMA PHYSICS LABORATORY, PRINCETON, NJ

Dr. DAVIDSON. Madam Chairperson, Mr. Brown, members of the committee, thank you for the opportunity to testify before this committee on behalf of the Princeton Plasma Physics Laboratory and in favor of a revitalized national effort to develop fusion energy.

Numerous recent advances in fusion have been made in laboratories in the United States and around the world. The TFTR tokamak at Princeton ionized deuterium gas, called plasma, has been heated to temperatures as high as 400 million degrees Celsius, well above the requirements for a power reactor. The TFTR tokamak and the Joint European Torus (JET) in Western Europe have achieved performance levels in deuterium plasmas suitable for producing substantial amounts of fusion power in a deuterium-tritium fuel mixture. Already, deuterium fusion reactions in TFTR produce 60 thousand watts of fusion power, and with the addition of tritium

to the reaction, the fusion power is expected to rise to more than 15 million watts.

In the DIII-D Tokamak at General Atomics in San Diego, the plasma energy density has been increased to 11 percent of the energy density in the confining magnetic field, comparable to reactor-level conditions. Progress continues to be made by laboratories, universities and industries in the United States and at laboratories around the world in developing materials, heating technologies and superconducting-magnet technology required for a practical fusion reactor.

What is now required is a national commitment to a sustained program to complete the research and development for a practical fusion power plant.

Following the recommendations of the Fusion Policy Advisory Committee, the Department of Energy has put before you a well-directed fusion energy program, and the President's budget for fiscal year 1992 would set the U.S. program on a course to develop fusion as a practical energy source. I strongly support the DOE's proposed program for fiscal year 1992, which has the following principal elements: Preparation for using deuterium-tritium fuel mixture in TFTR; increased design and R&D for the Burning Plasma Experiment (BPX), in preparation to begin construction in fiscal year 1993; participation in the Engineering Design Activity and related technology development for the International Thermonuclear Experimental Reactor (ITER); and a strong tokamak research program, including experiments on DIII-D at General Atomics, Alcator C-MOD at MIT, PBX-M at Princeton, and TEXT at the University of Texas.

A committed national effort in these four areas, together with increased industrial participation, will place the United States in a strong position to contribute to and benefit from the major fusion efforts in Western Europe and Japan.

While the Princeton Plasma Physics Laboratory has a number of efforts in fusion theory, diagnostic development, intermediate-scale tokamak experiments, let me focus briefly here on activities related to the TFTR tokamak, Burning Plasma Experiment, and the International Thermonuclear Experimental Reactor.

As I indicated earlier, the TFTR tokamak is a very successful experimental device. It has set world records in ion temperature (more than 400 million degrees Celsius) and in fusion power production (more than 60,000 watts in deuterium plasmas). Deuterium plasma conditions in TFTR extrapolate to performance levels in deuterium-tritium plasmas with fusion power exceeding 15 million watts.

Experiments with deuterium-tritium fuel are planned in TFTR for 1993-1994. These experiments are necessary to validate the expected properties of fusion plasmas under conditions where alpha-particle effects begin to play an important role. Deuterium and tritium will be the fuel used in BPX and ITER and the fuel most likely to be used in the first generation of commercial fusion reactors. Using D-T fuel, the TFTR tokamak is expected to increase its fusion power output by a factor of more than 300, to more than 15 million watts. The proposed funding will allow for machine and facility modifications that permit TFTR to enter this new regime be-

ginning in mid-1993, nearly two years ahead of the Joint European Torus (JET).

With regard to the Burning Plasma Experiment, the critical role of the Burning Plasma Experiment as the next major U.S. step in fusion energy development has undergone a detailed review by the Fusion Policy Advisory Committee. The Secretary of Energy has strongly endorsed the FPAC recommendations regarding BPX, as is evident in the proposed National Energy Strategy and in the DOE fusion budget submission to Congress for fiscal year 1992.

The mission of the BPX is to determine the physics behavior and operating characteristics of deuterium-tritium fusion plasmas under conditions of significant alpha-particle self-heating (alpha-particles and neutrons are the byproducts in the fusion process between deuterium and tritium), and to demonstrate the production of more than 100 megawatts of fusion power under controlled and environmentally-safe conditions. BPX will exceed TFTR performance by a substantial amount, and will provide the critical burning plasma data base for the successful operation of an engineering test reactor such as ITER.

BPX is organized as a National Fusion Project, and a distinguished team of engineers and physicists is being assembled to design, prototype, fabricate and install the BPX hardware. At the present stage of design and R&D, Ebasco, General Atomics, Grumman, McDonnell Douglas, SPAR Aerospace, Idaho National Laboratory, Los Alamos, MIT, Oak Ridge, and Princeton have major project management and technical responsibilities in key subsystems areas. An additional eight laboratories, universities and industries are presently involved in critical areas. The national character of the BPX Project will continue to increase significantly, particularly the prominent role of industry and universities, as we enter the detailed engineering design and construction phase. I estimate that approximately 80 percent of the total BPX Project costs will be in industry, including component design and fabrication. I also envision that major responsibilities will be assigned to industry, universities and the laboratories for tokamak and subsystem operations during the operating phase of the BPX.

And briefly with regard to the International Thermonuclear Experimental Reactor let me just say that the Princeton Plasma Physics Laboratory has provided important physics input to the ITER conceptual design activity. And, as Dr. Decker indicated to you, negotiations are under way to initiate the next phase of the ITER, the Engineering Design Activity.

Princeton Plasma Physics Laboratory offers it's full support to the U.S. candidate site for the EDA, namely San Diego. The Laboratory believes that, by hosting the ITER EDA, the United States would indicate its commitment both to a strong national program in fusion research, and to the maximum use of international collaboration to broaden the resources available for the future development of fusion technologies.

With your permission, a more detailed description of these and other program elements will be submitted for the record.

[The prepared statement of Dr. Davidson follows:]

Statement of Ronald C. Davidson
Director, Princeton Plasma Physics Laboratory
before the
U.S. House of Representatives
Committee on Science, Space and Technology
Subcommittee on Energy
March 13, 1991

Madame Chairperson, Members of the Committee: Thank you for the opportunity to testify before this Committee on behalf of the Princeton Plasma Physics Laboratory (PPPL) and in favor of a revitalized national effort to develop fusion energy.

As the modern world continues to consume a growing portion of its energy in the form of electricity, the successful commercialization of fusion could dramatically improve the global and national energy circumstances. Fusion offers the promise of energy that can be generated from deuterium and tritium -- isotopes of hydrogen -- with minimal environmental effects and no danger of catastrophic accidents. With fusion, there are no atmospheric emissions leading to acid rain and other air pollution, and no high-level nuclear waste. With improved technology for battery-powered vehicles, fusion could also make a major contribution to reducing our dependence on petroleum-based fuels for transportation. In the coming decades, the world will spend trillions of dollars on new plants to generate electricity. For the benefit of our children and grandchildren, I hope that many of those plants will be powered, like the Sun and the stars, by fusion.

The potential drawbacks of existing energy sources have been demonstrated forcefully in recent years. During the same period, numerous advances have been made in fusion research and development at laboratories in the United States and around the world. In the Tokamak Fusion Test Reactor (TFTR) at Princeton, ionized deuterium gas, called plasma, has been heated to temperatures as high as 400 million degrees Celsius, well above the requirements for a power reactor. The TFTR tokamak and the Joint European Torus (JET) have achieved performance levels in deuterium plasmas suitable for producing substantial amounts of fusion power in a deuterium-tritium fuel mixture. Already, deuterium fusion reactions in TFTR produce 60 thousand watts of fusion power, and with the addition of tritium to the reaction, the fusion power is expected to rise to more than 15 million watts. In the DIII-D tokamak at General Atomics in San Diego, the plasma energy density has been increased to eleven

percent of the energy density in the confining magnetic field -- comparable to reactor-level conditions. Progress continues to be made by laboratories, universities and industries around the world in developing the materials, heating technologies and superconducting-magnet technology required for a practical fusion reactor. Meanwhile the ability of scientists to predict the detailed behavior of fusion plasmas has improved significantly.

Nonetheless, there remain great scientific and technological challenges: for example, to determine the physical properties and operating characteristics of dense, high-temperature plasmas under conditions of significant fusion power production and self-heating by the alpha particles* produced in the D-T fusion process; to control fusion plasmas under long-pulse or steady-state conditions; to fabricate durable materials that can withstand the large heat loads and stresses in a fusion reactor; to inject fuel efficiently into the fusion chamber and to remove the helium ash after the alpha particles have given their heat to the plasma; and to develop reliable superconducting magnets for confining high-temperature plasmas. Solutions to these and related scientific and technological challenges will require the sustained effort of thousands of scientists and engineers for several decades.

The R&D record of our nation's fusion scientists and engineers has been outstanding at universities such as the Massachusetts Institute of Technology (MIT), the University of California at Los Angeles (UCLA), the University of Texas at Austin, the University of Wisconsin and Columbia University, at national laboratories such as the Princeton Plasma Physics Laboratory (PPPL), Oak Ridge National Laboratory (ORNL), the Los Alamos National Laboratory (LANL) and the Lawrence Livermore National Laboratory (LLNL), and at industries such as General Atomics, Ebasco Services Incorporated, Grumman, McDonnell Douglas, and Varian Associates. In the past fifteen years, tokamak performance, as measured by fusion power produced, has increased by more than a factor of a million! What is now required is a national commitment to a sustained program to complete the research and development for a practical fusion reactor.

Following the recommendations of the Fusion Policy Advisory Committee (FPAC), the Department of Energy has put before you a well-directed fusion energy program, and the President's budget for FY 92 would set the US program on a course to

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* Alpha particles (helium nuclei) and neutrons are the fusion products when deuterium and tritium nuclei collide under energetic conditions.

develop fusion as a practical energy source. I strongly support the DOE's proposed program for FY 92, which has the following principal elements:

- Preparation for using deuterium-tritium (D-T) fuel mixture in the Tokamak Fusion Test Reactor (TFTR),
- Increased design and R&D for the Burning Plasma Experiment (BPX), in preparation to begin construction in FY 93,
- Participation in the Engineering Design Activity (EDA) and related technology development for the International Thermonuclear Experimental Reactor (ITER), and
- A strong tokamak research program, including experiments on DIII-D at General Atomics, Alcator C-MOD at MIT, PBX-M at Princeton, and TEXT at the University of Texas.

A committed national effort in these four areas, together with increased industrial participation, will place the United States in a strong position to contribute to and benefit from the major fusion efforts in Western Europe and Japan.

It is unfortunate that fiscal constraints have forced the Department of Energy to narrow the focus of the national program, stopping work on some important alternate approaches, including the ATF stellarator at the Oak Ridge National Laboratory. As fusion proceeds toward a practical reactor, it may become prudent to reestablish a US capability in this area.

While the Princeton Plasma Physics Laboratory also carries out a vigorous program in fusion theory and computations, advanced diagnostic development, small-scale experiments on tokamak concept improvement, and graduate student training in support of the national fusion program, I will focus here on activities in the following principal areas pursued at PPPL:

- Tokamak Fusion Test Reactor (TFTR),
- Burning Plasma Experiment (BPX),
- Princeton Beta Experiment (PBX-M),
- International Thermonuclear Experimental Reactor (ITER).

1. Tokamak Fusion Test Reactor

The Tokamak Fusion Test Reactor (TFTR) has been the leading magnetic fusion device in the United States since it started operation in 1982. Designed to study the behavior of high-temperature plasmas confined by strong magnetic fields, and to develop enhanced-performance regimes of tokamak operation, TFTR contributes significantly to international fusion development and to the design of BPX, ITER, and future power reactors. TFTR will be the first magnetic fusion experiment in the world to fuse D-T fuel at high power levels. These experiments are scheduled for 1993-94 and will complete the machine's mission.

The TFTR is a very successful experimental device. In its nine-year history, TFTR has produced a number of scientific breakthroughs and has set world records in ion temperature (more than 400 million degrees Celsius) and in fusion power (more than 60,000 watts in deuterium plasmas). It has met or exceeded all of its design parameters, including field strength, plasma current and neutral-beam heating power, and it has attained all of the objectives that were established for operation with deuterium plasmas, including plasma temperature, and the product of plasma density, confinement time and temperature ($n\tau T$). These deuterium plasma conditions extrapolate to performance levels in deuterium-tritium plasmas with fusion power exceeding 15 megawatts.

TFTR continues to be a very productive machine, completing 7800 plasma pulses in its most recent run in 1990. TFTR scientists have produced experimental confirmation of the theoretically-predicted "bootstrap current," which can enhance the steady-state capability of fusion reactors. In addition, enhanced confinement regimes have been discovered on TFTR. And TFTR has made major contributions to the basic understanding of how energy and particles flow in hot, magnetized plasmas. TFTR is the most thoroughly diagnosed tokamak in the world; there are 54 separate diagnostic measurement systems monitoring the conditions of the plasma. More than 24 institutions -- universities, national laboratories, and industries -- collaborate in experiments on TFTR. Major collaborations are underway with the Oak Ridge National Laboratory (pellet injection, radio-frequency heating, confinement studies), the Massachusetts Institute of Technology (alpha-particle diagnostics, pellet injection), Columbia University (advanced plasma configurations with a high ratio of plasma energy density to magnetic energy density), the University of Wisconsin (plasma fluctuation diagnostics), and the Los Alamos National Laboratory (neutron diagnostics).

In the near term, the TFTR experimental program will emphasize the further optimization of deuterium plasma performance and the study, to the extent possible in deuterium plasmas, of certain new physical phenomena that are expected to arise in deuterium-tritium operation. A high-frequency heating system is being brought up to full power, in the expectation that it will enhance deuterium-tritium operation, both by providing additional heating of the core of higher density plasmas, and by producing a more intense population of alpha particles. Above a certain threshold, a population of alpha particles is predicted to give rise to new types of fine-scale plasma instabilities, which are presently being studied on TFTR using the beam-injected energetic ions to simulate the alpha particles. These studies are of critical importance both to the Burning Plasma Experiments (BPX) and to the International Thermonuclear Experimental Reactor (ITER). To improve power-handling capability, the TFTR has installed over a substantial area of its inner-vessel surface an array of tiles made of an advanced carbon-carbon composite material -- a technique also of considerable interest to BPX and ITER.

The TFTR experiments with deuterium-tritium (D-T) fuel, planned for 1993-94, are necessary to validate the expected transport and stability properties of fusion plasmas under conditions where alpha-particle effects begin to play an important role. Deuterium and tritium will be the fuel used in BPX and ITER and the fuel most likely to be used in the first generation of commercial fusion reactors. Using D-T fuel, the TFTR tokamak is expected to increase its fusion power output by a factor of about 300, to more than 15 million watts. Because tritium is a mildly radioactive isotope of hydrogen, and because the D-T reactions will produce significant neutron production, there are machine and facility modifications that must be completed before D-T experiments can begin. More than 75 detailed tasks must be accomplished, including the completion and certification of the tritium handling systems, the installation of a remote maintenance arm, and the preparation of the neutral beams and pellet injectors for using tritium. An improved analysis of shielding requirements has reduced the cost of the remaining D-T hardware from $60M to $30M. The funding levels proposed to DOE will allow TFTR to enter this new regime beginning in mid-1993, nearly two years ahead of the Joint European Torus (JET). The environmental certifications are in progress, and there is an active program to keep the local community informed of our plans in this area.

2. Burning Plasma Experiment

The critical role of the Burning Plasma Experiment (BPX) as the next major U.S. step in fusion energy development has undergone a detailed review by the Fusion Policy Advisory Committee (FPAC). The Secretary of Energy has strongly endorsed the FPAC recommendations regarding BPX, as is evident in the proposed National Energy Strategy and the DOE fusion budget submission to Congress for FY 92. The FY 92 submission requests an increase to $30M (from $16.7M in FY 91) for critical activities in BPX design and R&D.

The mission of BPX is to determine the physics behavior and operating characteristics of deuterium-tritium (D-T) fusion plasmas under conditions of significant alpha-particle self-heating, and to demonstrate fusion power production in excess of a hundred megawatts under controlled and environmentally-safe conditions. In this regard, BPX will exceed TFTR performance by about a factor of ten (100-500 megawatts rather than 15-30 megawatts of fusion power), and will provide the critical burning-plasma data base for the successful operation of an Engineering Test Reactor such as the International Thermonuclear Experimental Reactor (ITER). ITER, which will produce about a thousand megawatts of fusion power for much longer pulses, will begin D-T operation some seven years later than BPX and will emphasize the technologies and integrated engineering performance necessary to begin operation of a Demonstration Fusion Reactor (DEMO) by the year 2025.

Timely approval and operation of the BPX experiment will also play the important role of restoring the U.S. fusion program and the capability of U.S. industry to a position of international parity in fusion energy development.

The BPX is organized as a National Fusion Project, and a distinguished team of engineers and physicists is being assembled to design, prototype, fabricate and install the BPX hardware. At the present stage of design and R&D in the BPX project, Ebasco Services Incorporated, General Atomics, Grumman Space Systems Division, McDonnell Douglas Missile Systems, SPAR Aerospace, Idaho National Engineering Laboratory, Los Alamos National Laboratory, Massachusetts Institute of Technology, Oak Ridge National Laboratory, and Princeton Plasma Physics Laboratory have major project management and technical responsibilities in key subsystems of BPX. An additional eight laboratories, universities and industries are presently involved in critical technical areas. The national character of the BPX project will continue to increase significantly, particularly the prominent role of industry and universities, as we

enter the detailed engineering design and construction phase. I estimate that approximately 80% of the total BPX project costs will be in industry, including component design and fabrication. I also envision that major responsibilities will be assigned to industry, universities and the laboratories for tokamak and subsystem operations during the operating phase of BPX.

The design of the Burning Plasma Experiment has made significant progress during FY 91 and the project will undergo a major Conceptual Design Review during the last week of March. A technical review team has been organized by the Department of Energy (DOE), including committee members from Western Europe, Japan, the Soviet Union, Canada, and the United States. I am particularly grateful to the BPX Steering Committee, ably chaired by Professor David Baldwin of the University of Texas, for providing valuable ongoing technical input to the mission and design characteristics of BPX.

To summarize recent project accomplishments, the BPX tokamak design has progressed during the past year to a simpler mechanical configuration, less developmental magnet materials, and more conservative mechanical design criteria. These improvements in the tokamak design are warranted because of the central role BPX will play in the world fusion program. BPX is intermediate in scale and mission between the present large tokamaks (TFTR in the United States, JET in Western Europe, and JT-60 Upgrade in Japan), and an Engineering Test Reactor as embodied in the ITER design.

During the past year, extensive data has been collected on properties of the magnet materials for BPX (e.g., fatigue life) as part of the R&D program. This data has been used to validate the detailed structural analysis of the magnet performance. Small-scale prototyping of structural components, such as the vacuum vessel joints, has begun.

The BPX project is preparing to embark on a program to prototype the main elements of the tokamak. This prototyping activity will verify the design of the high technology components and facilitate fabrication of the hardware. A significant fraction of the funding requested for FY 92 is to support this important prototyping activity.

The Alcator C-Mod, a new high-field tokamak at the Massachusetts Institute of Technology, will begin operation later this year. This device will test several of the

physics concepts, operating scenarios, and magnet and heating technologies important for BPX operation.

The BPX project has been working with DOE and the Idaho National Engineering Laboratory (INEL) to complete the environmental review process for siting BPX in accordance with the National Environmental Policy Act (NEPA) requirements. The Department has determined that an Environmental Assessment (EA) is the appropriate documentation for the BPX environmental review. The INEL has been commissioned by the Department to carry out the environmental analysis and documentation for BPX, because of their extensive safety and environmental expertise. A draft of the EA has been reviewed by the Environmental Safety and Health (ES&H) Division in DOE. Detailed comments are being factored into the document by INEL with resubmittal to the Department expected in April.

The Conceptual Design Review to be carried out in March 1991, and the detailed design and prototyping activities that will continue through FY 92 will provide the basis for beginning BPX construction in FY 93.

I urge your endorsement of the full funding requested for the BPX project in FY 92, and look forward to approval of BPX construction in FY 93.

3. Princeton Beta Experiment

Studies of commercial fusion reactor designs, such as the ARIES program headed by Professor Robert Conn at the University of California at Los Angeles (UCLA), have identified opportunities for improving the tokamak concept, increasing the economic attractiveness, and decreasing the technological risks. These studies show that the cost of a fusion reactor is strongly affected by the ability of the magnetic configuration to confine high-pressure plasma, and by the efficiency of the system used to drive the plasma current during long-pulse operation.

Theoretical analyses of the stability of high-pressure plasmas have predicted a regime of improved confinement at plasma pressures beyond the conventional limits for tokamak operation. A fusion reactor operating in this "second stability regime" would yield large cost savings and increase engineering confidence. The advanced tokamak program on the medium-scale Princeton Beta Experiment (PBX-M) is aimed at the exploration of advanced techniques for entry into and exploration of the "second stability regime." In its most recent operation during FY 89, PBX-M used neutral

beams to heat strongly-shaped plasmas to the conventional pressure limit. In FY 90 and FY 91, radio-frequency systems in two different frequency ranges were added. In FY 92, PBX-M will use the high-power radio-frequency waves to tailor the spatial distribution of the plasma current and pressure to test the theoretical predictions for enhanced confinement at high plasma pressure. In addition, both the control and diagnosis of plasma behavior in PBX-M will contribute substantially to the resolution of technical issues in the ITER program, such as understanding the consequences of wall-currents in the control of plasmas subject to large-scale instabilities, and the feasibility of driving currents in the plasma edge by radio-frequency waves.

The PBX-M program benefits significantly from the participation of research scientists from several institutions, both domestic and international. The Massachusetts Institute of Technology (MIT) participates in the study of radio-frequency wave-driven plasma current and the exploration of paths to the "second stability regime." An effort by the University of California at Los Angeles (UCLA) focuses on studies of the influence of edge electric fields on plasma confinement. In FY 92, scientists from the Oak Ridge National Laboratory (ORNL) will participate in the study of fluctuations and transport and in analyses of the magnetic configuration in support of the second stability mission. Present and planned international participation in the PBX-M program includes European and Japanese exchanges on radio-frequency current-drive and heating.

4. International Thermonuclear Experimental Reactor

The project to design an International Thermonuclear Experimental Reactor (ITER) has successfully completed its first, three-year phase, the Conceptual Design Activity. A joint team, made up of physicists and engineers from the European Community, Japan, the Soviet Union and the United States, has produced a conceptual design which meets ITER's objectives of achieving controlled, extended burn of a deuterium-tritium plasma and demonstrating essential fusion technologies in an integrated reactor system. The ITER is planning to have two phases of experimental operation: a "physics phase," in which a long-pulse, ignited mode of plasma operation will be developed and optimized, and a "technology phase," which will be devoted to the integrated testing of the high-heat-flux and nuclear components required to utilize fusion power for practical purposes. The ITER device is much larger than the proposed Burning Plasma Experiment (BPX), since the superconducting coils needed for steady-state operation must be protected from the plasma's neutron flux by a shield and blanket. In ITER, a blanket is employed to approach self-sufficiency in the

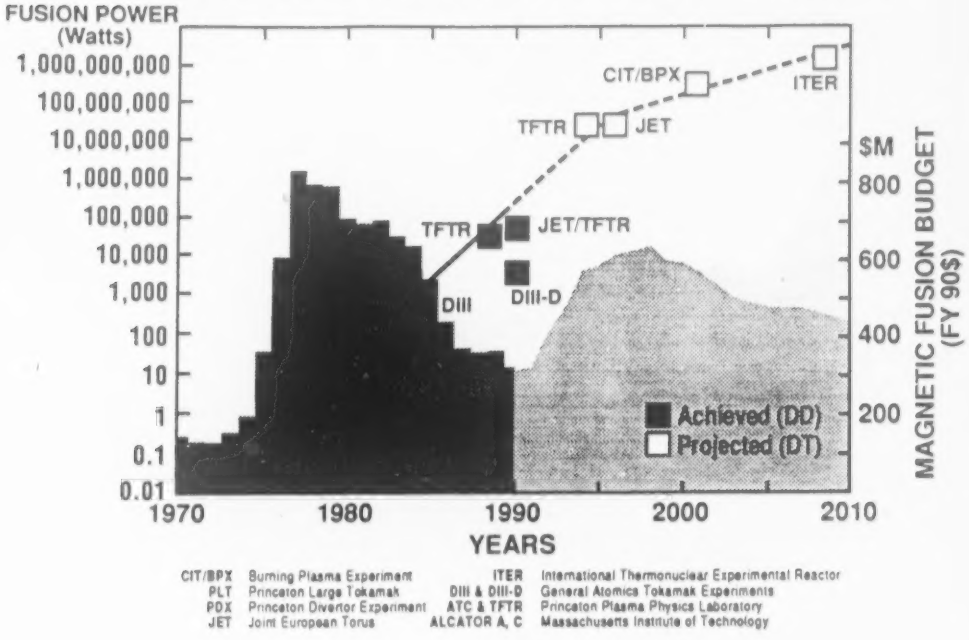
regeneration of tritium fuel. The ITER utilizes a vertically-elongated plasma configuration very similar to that in BPX and, likewise, it incorporates a magnetic divertor. The ITER conceptual-design team has also identified an extensive program of research and development, in both physics and engineering, that is needed to support an eventual decision to construct ITER.

The Princeton Plasma Physics Laboratory has provided important physics input to the ITER design, including the design-team leader, Dr. Douglass Post, with overall responsibility, both nationally and internationally, for physics aspects of the conceptual design. The Laboratory's major experimental tokamaks, the TFTR and PBX-M, have already contributed importantly to the ITER physics R&D program. Further contributions are expected: from TFTR, on aspects of plasma transport, neutral-beam current-drive, the use of carbon-carbon composites as limiter materials, and alpha-particle effects and tritium behavior in D-T tokamaks; and from PBX-M, on the control of strongly-shaped plasmas, operating limits, and the use of radio-frequency current-drive for plasma profile shaping.

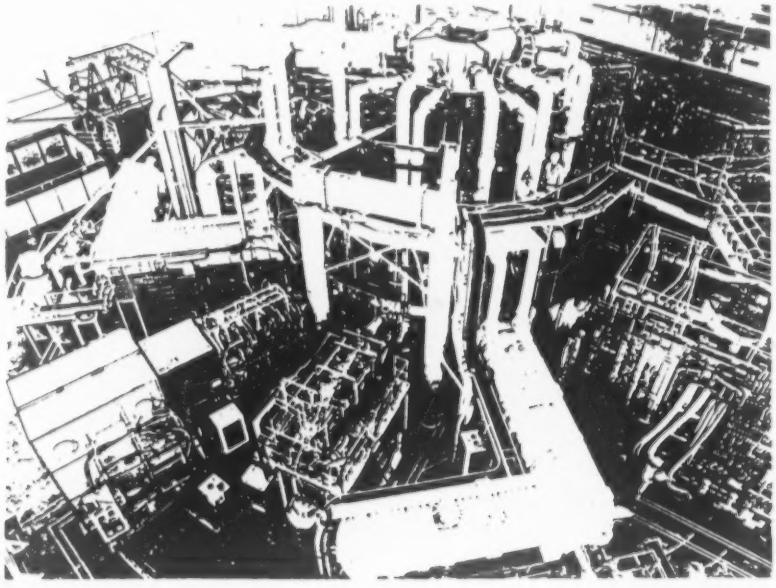
Negotiations are presently underway to initiate the next phase of ITER, the Engineering Design Activity (EDA). Unlike the previous phase, the EDA will require a full-time central design team, drawn about equally from the four partners but co-located at a single site, yet to be chosen. The Princeton Plasma Physics Laboratory offers its full support to the U.S. candidate-site for the EDA, namely San Diego. The Laboratory believes that, by hosting the ITER EDA, the United States would indicate its commitment both to a strong national program in fusion research, and to the maximum use of international collaboration to broaden the resources available for the future development of fusion technologies. The Laboratory hopes to continue to play a major role in the ITER activity.

That concludes my testimony. Again, thank you for the opportunity to make known my views on the US fusion program.

PROGRESS IN MAGNETIC FUSION POWER



CIT/BPX	Burning Plasma Experiment	ITER	International Thermonuclear Experimental Reactor
PLT	Princeton Large Tokamak	DIII & DIII-D	General Atomics Tokamak Experiments
PDX	Princeton Divertor Experiment	ATC & TFTR	Princeton Plasma Physics Laboratory
JET	Joint European Torus	ALCATOR A, C	Massachusetts Institute of Technology



TFTR Tokamak

TFTR HARDWARE CAPABILITIES

	DESIGN	ACHIEVED
a (m)	0.4-0.85	0.4 - 0.96
R (m)	2.1-3.1	2.1 - 3.1
ELONGATION	1.0	0.6 - 1.1
B_T (T) @ 2.48 m	5.2	5.2
I_p (MA)	3	3
P_{NB} (MW)	33	33
PULSE LENGTH (sec)	1.5	2

- *TFTR has achieved its hardware design requirements.*
- *Excellent operations in 1990. Best year ever.*

TFTR PLASMA PARAMETER RANGE

	DESIGN	ACHIEVED
T_i (0) (keV)	10	~35
T_e (0) (keV)	5-10	12
n_e (0) (10^{20} m^{-3})	1	5
n_e (0) τ_E T_i (0) (10^{20} m^{-3} sec keV)	4	4.4
Central Pressure (Atmosphere)		6.5

- *TFTR has met or exceeded the design values for these central plasma parameters.*

COLLABORATIONS ON TFTR

UNIVERSITIES

- Columbia University
- Cornell University
- Massachusetts Institute of Technology
- University of California at San Diego
- University of California at Irvine
- University of Maryland
- University of Texas
- University of Tokyo
- University of Wisconsin

US NATIONAL LABORATORIES

- Lawrence Berkeley Laboratory
- Los Alamos National Laboratory
- Oak Ridge National Laboratory
- Sandia National Laboratories

FOREIGN LABORATORIES

- Canadian Fusion Fuels Technology Project
- Japan Atomic Energy Research Institute
- JET Joint Undertaking, Abingdon, UK
- Kernforschungzentrum Karlsruhe
- Kurchatov Institute of Atomic Energy, Moscow
- Max-Planck Institute for Plasmaphysik, Garching

US INDUSTRIES

- Ebasco
- Fusion Physics and Technology, Inc.
- Grumman Advanced Energy Systems, Fusion Project
- General Atomics

MAJOR TFTR PHYSICS ACCOMPLISHMENTS

- Discovery of Supershot Enhanced Confinement Regime
  - World Record Ion Temperature (400 M ^{o}C)
  - World Record Deuterium Fusion Power (60 kW)
- Experimental Confirmation of the Theoretically Predicted "Bootstrap" Current Which Enhances the Steady-State Capability of a Tokamak.
- Experimental Confirmation of the Theoretically Predicted NeoClassical Effects on Parallel Resistivity.
- Optimization of Peaked Density Profiles Using Pellet Injection.
  - World Record $n\tau$ (Density X Confinement Time).
- First Measurements of Medium Scale Turbulence Using Recently Invented Beam Emission Spectroscopy.
- Simulation of Alpha Driven Alfven Wave Instabilities Using Neutral Beams.

TFTR D-T OBJECTIVES

STUDY CONFINEMENT AND HEATING OF D-T PLASMAS

DETERMINE EFFECTS OF ALPHA PARTICLES

- Single Particle Confinement.
- Alpha Driven Instabilities.
- Initial Indications of Alpha Heating.
- Develop Alpha Diagnostics.

DEMONSTRATE D-T TECHNICAL CAPABILITY

- Tritium Handling and Retention.
- Operation of Activated Machine.
- Diagnostics in Neutron Enivornment.

DEMONSTRATE D-T POWER PRODUCTION

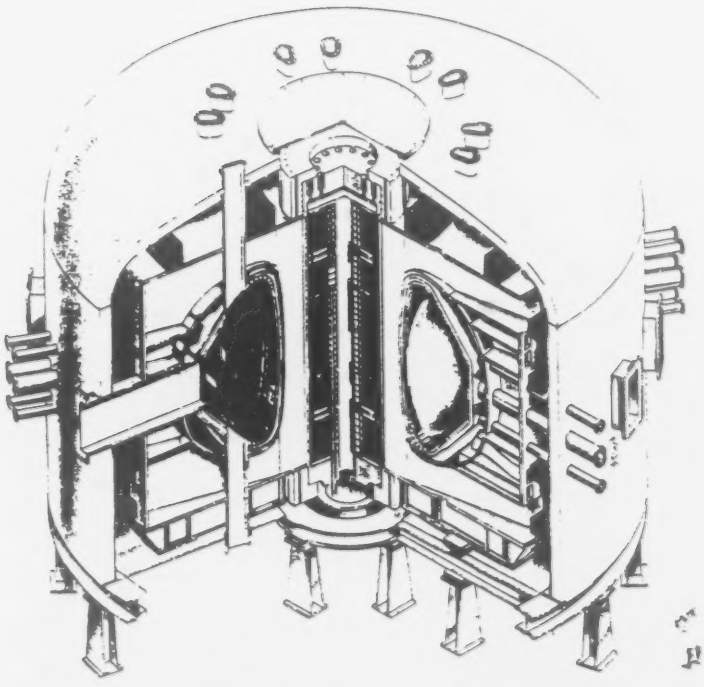
- Fusion Power ~ 15-30 MW.
- Center Fusion Power Density ~ 1 MW/m^3.
- Approximate Breakeven

MISSION AND OBJECTIVES OF BPX

The mission of the Burning Plasma Experiment (BPX) is to determine the physics of self-heated fusion plasmas and demonstrate the production of substantial amounts of fusion power.

The specific objectives are to:

- Demonstrate the production of fusion power in excess of 100 MW at reactor-level power densities.
- Determine the confinement physics, operational limits, and alpha-particle dynamics of self-heated plasmas with alpha power exceeding the auxiliary heating power.
- Demonstrate heating, fueling, and plasma handling techniques necessary to produce self-heated fusion plasmas with reactor-level power densities.
- Optimize plasma performance in the range between Q=5 and ignition, with fusion power up to 500 MW.



BURNING PLASMA EXPERIMENT

CHARACTERISTICS OF BPX

High Field

High Plasma Current

Low Duty Factor

Deuterium - Tritium Fuel

RF Heating

Copper Coils Cooled by Liquid Nitrogen

Remote Maintenance

Major Radius (R)	*2.59 m*
Minor Radius (a)	*0.79 @ midplane*
Elongation	*~2.0*
Magnetic Field on Toroidal Axis (B_T)	*7.6 T*
Toroidal Plasma Current (I_p)	*10 MA*
Flat-top Duration for Field and Current	*10 s*
Ion-Cyclotron Heating Power	*20 MW @ 60-90 MHz*
Fuel Pellet Injection Speed	*4-5 km/s*

BPX STATUS

- The BPX design has been continually developed and refined - with emphasis on simplicity, robustness, and high performance.
- An extensive R&D program has been carried out that supports the BPX design.
- A 2000-activity linked schedule has been developed for the project.
- Management plans and systems have been approved and are in place for the construction phase.
- A thorough environmental assessment has been developed by INEL. INEL is modifying the EA according to DOE comments.
- The next step in the project is to begin prototyping of major components.

BPX IS A NATIONAL PROJECT

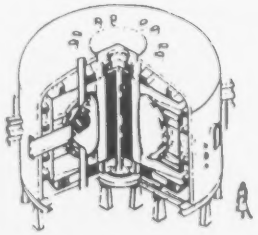
PHYSICS

Argonne National Laboratory
General Atomics
Hunter College
Lawrence Livermore National Laboratory
Massachusetts Institute of Technology
New York University
Oak Ridge National Laboratory
Princeton Plasma Physics Laboratory
University of California, Los Angeles
University of Illinois
University of Wisconsin, Madison

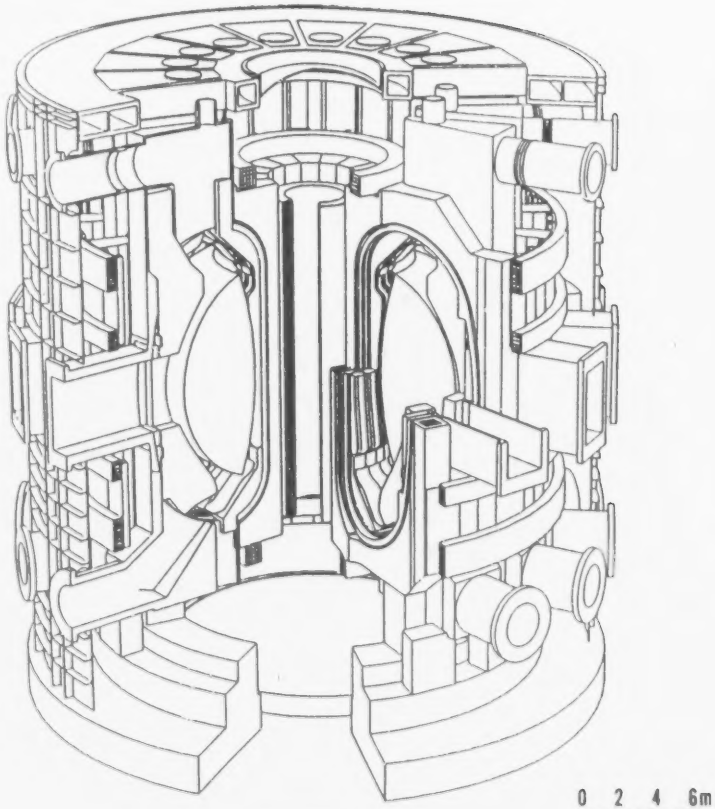
ENGINEERING

Ebasco Services Incorporated
Grumman Space Systems Division
Idaho National Engineering Laboratory
Lawrence Livermore National Laboratory
Los Alamos National Laboratory
Massachusetts Institute of Technology
McDonnell Douglas Missile Systems Co.
Oak Ridge National Laboratory
Parsons Brinkerhoff
Princeton Plasma Physics Laboratory
SPAR Aerospace

BPX / ITER COMPARISON



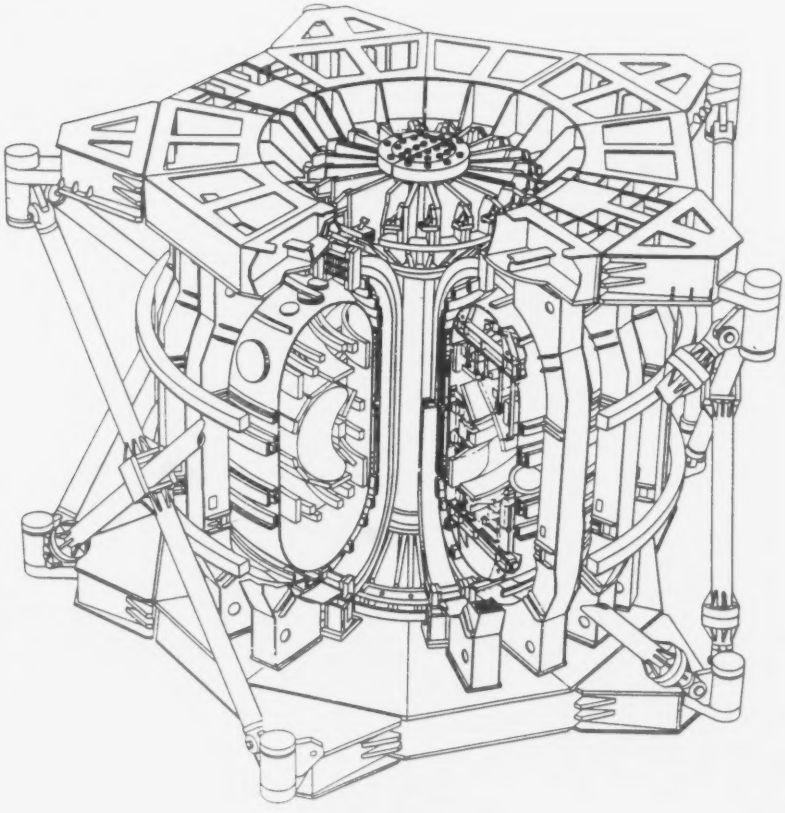
BPX



ITER

ROLES OF THE ADVANCED TOKAMAK PROGRAM

- Invention and experimental investigation of features that may enhance the performance and economic attractiveness of a tokamak reactor.
- Development and demonstration of advanced auxiliary techniques that can enhance the performance of future tokamaks such as the Burning Plama Experiment (BPX), the International Thermonuclear Experimental Reactor (ITER), and the Long-Pulse/Steady-State Tokamak (LP/SST).



PBX-M

PBX-M GOALS
In Terms of Advanced Tokamak Issues

Concept Improvements

- Ballooning Mode Stabilization in 2nd Stability Regime
- Kink Mode Stabilization
- Enhanced Confinement (H, 2nd, Profile-effects)

Tool-Building

- j(r)-control
- p(r)-control
- Shape-control
- Close-fitting Wall
- Edge-electric Fields [with UCLA]

Approaches

- High-β at High-β / (I / aB) and q(0) ~ 1
- High-β_p in 2nd Stability [with MIT]

Other Applications

- Disruption Characterization and Control
- R/a-Scaling

SUMMARY

- Advanced Tokamak Program offers high-leverage opportunities for developing reactor-relevant improvements
- PBX-M Program can contribute in unique ways to the improvement of the tokamak concept
  - Assessment of the accessibility of second stability at high-β [critical to validation of ARIES II and III concepts]
  - Assessment of high-β_p path to second stability [emphasis of PPPL / MIT collaboration]
  - Enhancement of confinement in second stability [PPPL / MIT collaboration]
  - Enhancement of confinement by profile control
  - Enhancement of confinement by electric fields [PPPL / UCLA collaboration]
  - CIT / BPX and ITER Physics R&D

Mrs. LLOYD. Without objection. Thank you very much.
Dr. Parker?

STATEMENT OF DR. RONALD R. PARKER, DIRECTOR, PLASMA FUSION CENTER, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, MA

Dr. PARKER. Thank you, Madam Chair. Madam Chair, members of the subcommittee, as you've heard, during the past year the Fusion Policy Advisory Committee, or FPAC, has extensively reviewed the Magnetic Fusion Energy, or MFE, Program. There are three results of critical importance that I'd like to comment on that came from the FPAC Report.

The first is an unequivocal approbation of the results and progress which have been made in the MFE Program during the past several years. You've heard some of these results referred to in previous testimony, I will not go into any more detail here.

The second is an assessment based on accomplishments, that based on accomplishments, the MFE Program is ready to initiate a goal-oriented fusion energy development program.

And the third is a plan for carrying out that program. I'd like to make a few comments on the plan here, particularly as that plan relates to the 1992 budget request. There are two key elements of near-term significance in the FPAC plan: The Burning Plasma Experiment, or BPX, and an engineering test reactor. In the view of the U.S. community, the engineering test reactor is the proper role of the ITER.

The FPAC had difficulty deciding which initiative, the BPX or ITER, should have higher priority. There was good reason for this. The fact is that they're both required in order to provide the technical and physics data base to build a DEMO and operate it by 2025. In order to build the DEMO, we will have to rigorously adhere to the schedule set up by the FPAC, and this means that we must anticipate a growing fusion budget in the next five years, perhaps to the level as recommended by FPAC of about $600 million. The fiscal year 1992 request of $337 million, while less than that recommended by FPAC, is at least a step in the right direction.

With regard to the Burning Plasma Experiment, I have consistently and vigorously supported this initiative for several years. I continue to maintain my conviction about the importance of this project. Over the years the objectives in design for BPX have evolved. As you know, it was known earlier as the CIT. One factor in the process has been the desire to ensure, with a very high degree of confidence, that the objectives set out for the device would be fully met. Not surprisingly as we have approached an evermore capable and realistic design, the result has been an increase of size, complexity and cost. Nevertheless, I believe that the increased scope and enhanced capability of BPX, relative to the earlier more primitive CIT designs, is well worth both the delay in construction and the increase in cost.

The role of ITER is presently undergoing an international review. The U.S. position, as I mentioned earlier, is that ITER should serve primarily as an engineering test reactor, and I support that view. In consequence, the mission of the BPX is clear,

namely, to support ITER by providing a scientific data base which is required to produce and control burning plasmas. If we are successful in obtaining consensus among our partners that ITER should primarily be an ETR, then expansion of the scope of the BPX might be appropriate. In any event, it is imperative that the goals of the BPX be consistent and consonant with those of the ITER. This will require a closer coordination between the architects of these projects, a process that might be conducive to engaging international support of the BPX.

The ITER is a very attractive opportunity to realize the objectives of an engineering test reactor at minimum cost to the U.S. taxpayer. In addition to furthering the engineering design, the Engineering Design Activity will engender the R&D required to support a construction decision. This will provide a much needed stimulus to the development of technologies which are critically needed, not only for ITER, but also for the DEMO. Among these technologies, I would single out large scale superconducting magnets, an area of special interest to MIT, where we have a very substantial effort involving magnets for MHD energy conversion and propulsion, high energy and condensed matter physics research, magnetically levitated transportation, and magnetic resonance imaging. This is a fertile area which has and will continue to spawn technology transfer from fusion R&D to the private sector.

At the present time, negotiations are underway to determine the main site for the EDA design work. I urge our negotiating team from the OFE to do all in their power to bring the site to the United States. I certainly support Congressman Brown's comments in that regard.

While FPAC's recommendation to initiate a goal-oriented fusion program provides useful direction, and is generally welcomed, the consequences of narrowing the program must be acknowledged. Simply put, the effect of narrowing is to increase risk; if narrowed too much, the risk will become unacceptable.

The recent action of the Congress in cutting $50 million from the MFE Program at the beginning of this fiscal year is regrettable. I must add here that I'm very grateful to you, Madam Chairman, and the members of this committee for their efforts in partially restoring this cut. In effect, in order to save money for this fiscal year, the Congress compromised an investment of a considerably larger sum of money which had already been spent in previous years. The unplanned closeout of facilities which are either under construction, about to operate, or are in a fully productive mode of operation is very wasteful and sets a very dangerous precedent. The budget action caused irreparable damage to the morale of everyone in the program, and I might add especially to the graduate students at my institution who ideally believe that developing fusion energy is a worthwhile and noble career goal.

Of particular concern to me is the shutdown of the Advanced Torroidel Facility [ATF] at Oak Ridge, a device that was producing important data. I urge the Department to review the merits of this program and, if the results are as persuasive as I think they will be, to restart operation of ATF as soon as possible and to expeditiously complete it's mission.

Finally, I would like to close with a few comments on the cost of developing fusion energy. The FPAC-recommended plan calling for operation of a DEMO by 2025 can be estimated to cost an additional $20 billion in fiscal year 1990 dollars. Thus far, about $11 billion has already been invested in fusion research. This leads to a total expected investment of about $30 billion. This is less, actually, than the $36 billion estimate made by ERDA in 1976, and reflects both a more focused plan and one that relies more heavily on international collaborations.

The $20 billion additional investment required to complete the development of fusion might be compared favorably to another energy-related cost, namely the cost of the Persian Gulf war. Moreover, it is actually a very reasonable expenditure considering the market that fusion energy will serve. Over the next 60 years the utility industry is expected to spend over $4 trillion dollars in new capital investment. Surely an R&D outlay of less than one percent of this investment is attractively modest on purely economic grounds.

Madam Chair and members of the committee, I would like to sincerely thank you for your steadfast support. It has been a critical element in the progress that we have made. The Department has formulated a plan to efficiently reach fusion's potential as an unlimited, economic and environmentally attractive source of energy. I ask that you endorse the Department's plan and begin by your approval of the President's fiscal year 1992 budget request and your support of this level during the appropriation process.

Thank you for the opportunity to present my views this morning.

[The prepared statement of Dr. Parker follows:]

Magnetic Fusion Energy Program Status and Direction

Statement by
Dr. Ronald R. Parker
Director, Plasma Fusion Center

Massachusetts Institute of Technology
Cambridge, MA

Presented to
The Subcommittee on Energy Research and Development
Committee on Science, Space and Technology

U. S. House of Representatives
Washington, D. C.

March 13, 1991

Madam Chair, Members of the Subcommittee:

I am Ronald Parker, Director of MIT's Plasma Fusion Center. I am very grateful for your invitation to convey my views on the status and direction of the U.S. magnetic fusion energy program.

Why Pursue Fusion Energy?

Nearly 90% of the world's energy needs are today supplied by fossil fuels: oil, natural gas and coal. At the present rate of consumption, it has been estimated that economically recoverable sources of oil would be depleted in about 60 years, a time which could be shortened by as much as a factor-of-two by continued world population growth and economic expansion. Since the energy content of the remaining economically recoverable natural gas is only about equal to that of oil, it is reasonable to assume that coal will become the fossil fuel of choice, particularly for baseload electricity generation, during the early part of the next century. This trend is already evident in the utility industry where coal is now used to supply about 55% of the energy used in electricity production, compared with 45% at the time of the oil embargo in the mid-1970's.

From an environmental perspective, continued reliance on fossil fuels, especially coal as it provides a larger share of the world's energy needs, is potentially catastrophic. In the near term, one foresees continued and exacerbated problems with pollution and acid rain, caused by the emission of particulates, SO_2 and NO_x. In the long term, one faces the prospect of global warming due to the buildup of CO_2 and other greenhouse gasses in the atmosphere. Clearly, substantial production of energy in the next century by methods which do not involve the combustion of fossil fuels will be needed. The long time inherent in developing new large-scale energy technologies, on the order of 30 years, adds a dimension of urgency to accelerating the development process.

Among the non-fossil fuel alternatives, fusion energy is especially attractive. It will be extremely efficient as only about one ton of deuterium is required to produce 1000 megawatts of electricity per year, compared to over one million tons of coal; it is inexhaustible since, for example, deuterium is easily extracted from water; it is safe since the fusion reactions occurring in a reactor will cease within a few seconds of interrupting the flow of fuel; and it is environmentally attractive since fusion reactions produce no gases to poison the atmosphere, nor long-lived radioactive isotopes to be buried with uncertain geological consequences. The high fuel-mass efficiency, more than a million times that of fossil fuels, translates to huge economies in the mining and transporting of fuels and in the creation of waste. The U.S. consumption of electrical energy is approximately 300 GW-year and is expected to increase in the future in proportion to the GNP as it has for the past 15 years. The benefits to public health and the environment of high fuel-mass efficiency provide powerful arguments for generating a growing fraction of energy needs for the 21st century by fusion power.

Fusion Policy Advisory Committee Report

During the past year, the Fusion Policy Advisory Committee (FPAC) has extensively reviewed recent progress made in the Magnetic Fusion Energy (MFE) program and, based on an assessment of the technical readiness, has recommended a plan for the development of fusion energy leading to commercial generation of fusion power by the by the middle of the next century. There are three principal results which come from the FPAC report and which are of crucial importance to the MFE program. One is the unequivocal approbation of the progress which has been made by the magnetic fusion program during the past several years. A second is the assessment that, based on accomplishments, the magnetic fusion energy program is ready to initiate a goal-oriented fusion energy program. And the third is the recommendation of a plan for magnetic fusion energy development including principal required facilities, near term funding levels and an identification of goals by which progress can be measured.

It is extremely frustrating to those of us working in the field to sense that there is still a perception among many, particularly in the halls of Congress, that there has been little progress in fusion research over the years. While not denying that the fusion community has on occasion oversold the significance of its results, it is still categorically true that progress in fusion research has been outstanding. The maximum temperatures achieved in TFTR and JET, our most powerful fusion devices, are many times higher than the temperature in the core of the sun, and even higher than required for a practical fusion reactor. The all important temperature-density-confinement-time product is 10,000 times higher than it was at the advent of the tokamak era in 1970, and is now within only a factor of 10 of what is needed for a practical fusion power plant. (This factor of 10 can be achieved by increasing the size and/or field of the experimental reactor.) These achievements will culminate in mid-1993 with the introduction of tritium fuel in TFTR where we expect, assuming no further improvement in plasma performance, that the fusion power produced will be within a factor-of-two of the power injected to sustain the plasma. In addition to the technical value of these results, we look forward to the value of fulfilling the commitment made by the fusion community to the Congress when TFTR was authorized. This achievement, perhaps more than any other yet realized, should help to buttress credibility to our program.

Two key elements in the FPAC plan are the Burning Plasma Experiment (BPX) and the Engineering Test Reactor (ETR). In the former, the scientific data base required to produce and sustain a burning plasma, i.e., a plasma that has all of the characteristics of those that will be found in the core of a fusion reactor, will be assembled. In the latter, the technologies required to produce such plasmas in a practical reactor and to convert the fusion power these plasmas produce to useful heat, will be developed. In my view, which is shared by many in the U.S., an ETR is the proper role of ITER, the International Thermonuclear Experimental Reactor. The FPAC had difficulty in deciding which initiative, BPX or ITER, should have higher priority. This is an obvious consequence of the fact that *both BPX and ITER are necessary for designing and constructing a demonstration power reactor (DEMO) by the year 2025. Also, meeting this goal will require rigorous adherence of the schedule for BPX and*

ITER as proposed by FPAC. An increased fusion budget growing to about $600M per year will also be required.

The Burning Plasma Experiment

I have consistently and vigorously supported the construction of the burning plasma experiment as the next major U.S. magnetic fusion program initiative for at least the last six years. Evidence for my enduring support can be found in testimony presented to this committee in 1985 and 1989, and in testimony presented to Congressman Roe's subcommittee in October, 1989. I continue to maintain my conviction about this project.

Over the years, the objectives and design for the BPX (which was known earlier as the CIT) have evolved. One factor in this process has been the desire to ensure, *with a degree of confidence unprecedented in the history of the magnetic fusion program*, that the objectives set out for this device will be met. Another factor has been the effort to find the proper niche for the device in the context of the need of the future U.S. program and, of equal importance, requirements of the international fusion effort. Not surprisingly, as we have approached an ever more capable realistic design, the response to these design drivers has been an increase in size, complexity and cost. Nevertheless, I believe that the increased scope and enhanced capability of the BPX, relative to the earlier more primitive CIT designs, is well worth both the delay in initiating construction and the increase in cost.

The objectives of the BPX and ITER should be clear and complimentary. The role of ITER is presently undergoing international review. The U.S. position, as indicated above, is that ITER should serve primarily as an engineering test reactor. Consequently, the mission of the BPX is quite clear, namely, to provide the scientific data base required to produce and control burning plasmas. If we are successful in obtaining consensus among our partners that ITER should primarily be an ETR, then expansion of the scope of the BPX might be appropriate. *In any event, it is imperative that the goals of the BPX be consonant with those of ITER.* This will require closer coordination between the architects of these two projects, a process that might be conducive to engaging international support of BPX.

The International Thermonuclear Experimental Reactor

Negotiations presently underway will likely culminate in a decision by the U.S., Japan, the European Community and the U.S.S.R. to enter into the Engineering Design Activity (EDA) phase of ITER. The ITER process has been highly successful during the three year conceptual design phase and serves as a paradigm for future international scientific collaborations. The Department of Energy, and specifically the Office of Fusion Energy, should be commended for its outstanding efforts in this regard.

The ITER activity represents a very attractive opportunity to realize the objectives of an engineering test reactor at a minimum cost to the U.S. taxpayer. The process has brought together top scientific and technical talent from around the world to collaborate on an exciting and important venture. In addition to furthering the

engineering design, the EDA will engender the R&D required to support a construction design. This will provide a much needed stimulus to the development of technologies which are critically needed, not only for ITER, but also for the DEMO. Among these technologies, I would single out large scale superconducting magnets, an area of special interest to MIT, where we have a very substantial effort involving magnets for MHD energy conversion and propulsion, high energy and condensed matter physics research, magnetically levitated transportation, and magnetic resonance imaging. This is a fertile area which has and will continue to spawn technology transfer from fusion R&D to the private sector.

At the present time, negotiations are underway to determine the main site for the EDA design. Through the hard work and capable leadership of General Atomics, the U.S. has put forward an extremely attractive site in San Diego. I fully support this effort and urge our negotiating team from OFE to do all in their power to bring the site to the United States.

Alcator C-MOD

The past successes of the Alcator tokamaks at MIT have demonstrated the value of the high-field, high-density compact approach to plasma confinement. This approach is now embodied in the BPX, which offers the most promising and economic means to explore fundamental issues associated with burning fusion plasmas. While the step from Alcator C to BPX constitutes a large extrapolation in size, power, current and other factors, Alcator C-MOD provides a prudent, cost-effective and appropriate way to fill in our understanding of the intervening parameter space similar to using a wind tunnel test in developing a new aircraft design. It satisfies the need for further physics research at an experimental scale short of that required for fully burning plasmas. The flexibility inherent in a modest facility of this type can be used to explore different options and possibilities which the necessarily less flexible burning plasma experiment cannot.

In addition to its role as prototype for BPX, Alcator C-MOD represents the next logical step in high-performance tokamak research. Unlike its predecessor, Alcator C, it incorporates modern tokamak design features such as shaped non-circular plasma cross-section, a poloidal divertor, and dominant auxiliary heating and ensuing power loading of the walls. These features will allow it to pursue the investigation of high-density, high-temperature, ion-cyclotron-heated plasmas, with the goal of understanding the physics of RF heating, confinement, stability, impurity control, fueling, shaping and heat removal of high performance tokamaks. While the initial operating program has been developed to optimally provide information critically needed to confirm the BPX design, the data obtained from Alcator C-MOD will also be useful to ITER. A particular area of common concern is the characterization of the divertor performance. The addition of RF current drive would further enhance the relevance of Alcator C-MOD to ITER. Final contract approval for the construction of Alcator C-MOD was received in April 1987 and it is scheduled to start plasma operation in mid-Spring 1991. It is the only new tokamak of major programmatic importance begun in the U. S. during the 1980's.

The Narrowing of the MFE Program

While FPAC's recommendation to initiate a goal-oriented fusion program provides useful direction, and is generally welcomed, the consequences of narrowing the program, particularly within the present budget strictures, must be acknowledged. Simply put, the effect of narrowing is to increase risk; if narrowed too much, the risk will become unacceptable.

The goal of the MFE program is not simply to build *a* reactor, but rather to build one that is *economically competitive and environmentally attractive.* Narrowing the program too rapidly will not only exclude potentially attractive alternatives to the tokamak, but will prevent an adequate development of the science base necessary to optimize the tokamak itself. With regard to the tokamak science base, I strongly reaffirm my support for the Transport Initiative, a community-wide focussed effort to develop fundamental understanding of heat and particle transport in tokamaks. I also recommend that additional initiatives be formed, along similar lines, to address other key aspects of tokamak operation such as disruption control and divertor optimization. These issues are particularly important for ITER and have direct bearing on the overall attractiveness of the tokamak reactor.

The recent action of the Congress in cutting $50M from the MFE program at the beginning of this fiscal year is regrettable, in fact, unfathomable. In effect, in order to save money in this fiscal year, the Congress compromised an investment of a considerably larger sum of money already spent in previous years. Setting aside the arguments over technical merit, the unplanned closeout of facilities which are under construction, about to operate or in a fully productive operating mode is extraordinarily wasteful and sets a very dangerous precedent. This budget action caused irreparable damage to the morale of everyone in the program, especially the new generation of graduate students who idealistically believe that developing fusion energy is a worthwhile and noble career goal.

Of particular concern to me is the shutdown of the ATF, a device that was producing important data. The stellarator or torsatron concept remains a leading alternative to the tokamak, one that it permits highly efficient steady-state operation. The ATF was also producing results which had direct bearing on the physics of tokamaks. I am somewhat encouraged by the Department's decision to consider the ATF "moth-balled" rather than cancelled. I urge the Department to review the merits of this program and, if the results are as persuasive as I believe they will be, to restart operation of ATF as soon as possible.

The Cost of Fusion Energy Development

Finally, I would like to close with a few comments on the cost of developing fusion energy. The FPAC-recommended plan calling for operation of a DEMO by 2025 can be estimated to cost about $20B (FY 1990 dollars)[1]. Thus far, about $11B has already been invested on fusion research, leading to a total expected investment of about $31B. This is less than the $36B estimate made by ERDA in 1976, and reflects

[1] The numbers and arguments given here are based on those presented to FPAC in a plan developed by fusion community program leaders.

both a more focused plan and one that relies more heavily on international collaborations.

The $20B investment required to complete the development of fusion might be compared favorably to another energy-related cost, namely that of the Persian Gulf war. Moreover, it is actually a very reasonable expenditure considering the market that fusion energy will serve. The installed U. S. electrical capacity is about 670 GW; assuming a 2% per year growth (for the past 15 years, electrical power consumption has tracked the GNP and is expected to continue to do so) one can calculate an estimated required capacity of 2200 GW by the year 2050. At an estimated cost of $2B per GW, this implies a capital investment of $4.4 trillion! Surely an R&D outlay of less than 1% of this investment is attractively modest on purely economic considerations.

Mrs. LLOYD. Thank you very much for your testimony.
Dr. Bangerter?

STATEMENT OF DR. ROGER O. BANGERTER, GROUP LEADER, HEAVY ION FUSION ACCELERATOR RESEARCH, LAWRENCE BERKELEY LABORATORY, BERKELEY, CA

Dr. BANGERTER. Mrs. Lloyd, Mr. Brown, and members of the subcommittee, I'm very pleased to be able to speak to you today about the Heavy Ion Fusion Accelerator Research Program. As you've heard, there are two main approaches to fusion energy: inertial fusion and magnetic fusion. In magnetic fusion the burning fuel is contained by magnetic fields. In inertial fusion the fuel is placed in a small target, about the size of a pea, and the target is ignited by intense beams from a laser or a particle accelerator. The device that produces these intense beams is referred to as the driver. And, of course, in the case of heavy ion fusion, the heavy ion accelerator is the driver. There are two important questions for both magnetic and inertial fusion, there have always been two important questions. The first question is scientific feasibility. That is, can devices be made to produce more energy than they consume? I think, based upon the progress that has been made in both inertia fusion and magnetic fusion during the last few years, that this question will certainly be answered affirmatively.

The second question is perhaps more difficult, and that is, can fusion devices be made that make good economic, engineering and environmental sense? And I believe the outlook for that is very favorable, but on the other hand a lot of research will be required to firmly establish the answer to that question.

I'd like to speak just briefly about the question of scientific feasibility for inertial fusion. Inertial fusion is related to questions of nuclear defense, and therefore has been supported by the Department of Energy through the Assistant Secretary for Defense Programs. There's been remarkable success in that program during the last decade, both at the Nova Laser at the Lawrence Livermore National Laboratory, and also in a program known as the Halite/Centurion Program that's being conducted at the Nevada Test Site. And based on that success, the Fusion Policy Advisory Committee has recommended the establishment of a new Inertial Fusion Energy Program be located in the Office of Fusion Energy, as Dr. Decker has already mentioned. And I am pleased that heavy ion fusion has been selected as the cornerstone of that new Inertial Fusion Energy Program.

It is interesting to ask why a new program is needed when an inertial fusion program does exist in the Department of Energy and Defense Programs. The existing program has concentrated mostly on scientific feasibility—on the target physics—and has built a number of drivers—lasers and light ion accelerators—to ignite the targets. These drivers are excellent for near-term research, but they typically have a very low pulse repetition rate, a few per day. For commercial applications, one requires a driver that has a very high pulse repetition rate, perhaps 10 per second or so. The driver also has to be very reliable, very durable and make good engineering sense. Nearly all high-level review panels during

the last decade have identified heavy ion accelerators as a leading candidate for commercial power production. And as a consequence, we have proposed a program of heavy ion fusion accelerator research that does lead to inertial fusion power production in about 2025, consistent with the FPAC recommendations, and also consistent with the new National Energy Strategy. The first part of this program—the first phase of this program—we refer to as the Induction Linac Systems Experiments. It's a series of experiments. ILSE for short.

And our long-term plans are consistent with the National Energy Strategy. They call for an intermediate facility between ILSE and a full-scale fusion driver near the end of this decade, and then early in the next century the construction of a large driver that would be capable of igniting targets and serving as the driver for a prototype power plant.

The Department of Energy's budget contains $9 million for fiscal year 1992 for the Inertial Fusion Energy Program. Of that, about $1.85 million is earmarked for ILSE design.

With your support, we believe it will be very successful. We believe that the ILSE program is a sound scientific program, and we're looking very much forward to working with you on that. I'd be happy to answer any questions.

[The prepared statement of Dr. Bangerter follows:]

HEAVY ION ACCELERATOR RESEARCH FOR INERTIAL FUSION ENERGY PRODUCTION

Testimony

to the

Subcommittee on Energy

Science, Space, and Technology Committee

by

Dr. Roger O. Bangerter
Group Leader
Heavy Ion Fusion Accelerator Research
Lawrence Berkeley Laboratory

March 13, 1991

Chairman Lloyd and Members of the Subcommittee:

I am pleased to have the opportunity to talk to you about the Heavy Ion Fusion Accelerator Research Program at Lawrence Berkeley Laboratory. The goal of our program is to develop accelerators for fusion energy production. Heavy ion fusion, like laser fusion, uses intense beams to ignite small targets containing thermonuclear fuel. The burning fuel is confined by its own inertia. In the other main approach to fusion, the burning fuel is confined by magnetic fields. Both inertial and magnetic fusion offer the promise of safe, environmentally benign energy and a nearly limitless supply of fuel.

At the inception of both fusion programs the fundamental scientific question was:

"Can fusion devices be made that produce more energy than they consume?"

Progress in magnetic and inertial fusion during the last decade has convinced nearly all scientists that this question will be answered affirmatively. The important question is now:

"Does fusion make engineering, environmental, and economic sense?"

Much research will be required to answer this second question, but the outlook is favorable.

Let me briefly expand on the answer to the first question, scientific feasibility. In inertial fusion, as noted above, small targets containing thermonuclear fuel are ignited by intense laser or particle beams. The targets explode, creating bursts of energy that can be contained in a target chamber or reactor. The targets typically have a radius of a few millimeters and the target chamber has a radius of a few meters. The beams from the laser or particle accelerator (the driver) are focused by lenses outside the chamber onto the target located at the center of the chamber.

The creation of small thermonuclear microexplosions is relevant to nuclear defense and the Department of Energy, through its Defense Programs, has supported the construction of lasers and accelerators to address the scientific feasibility of inertial fusion. Based on the progress to date, it appears very likely that Defense Programs will fully establish the scientific feasibility of inertial fusion within about a decade. Indeed the Halite/Centurion program conducted at the Nevada Test Site using nuclear explosives has already put to rest fundamental questions about the basic

feasibility of inertial confinement fusion. Research on reactors, target factories, and drivers is the new element that must be added to the ongoing Inertial Fusion Program to develop inertial fusion for commercial energy. To accomplish this research, the Secretary of Energy's Fusion Policy Advisory Committee[1] recently recommended the creation of a new Inertial Fusion Energy (IFE) Program in the Office of Fusion Energy. Development of heavy ion accelerators is the cornerstone of the recommended program. Reactor research and materials studies are other important elements.

I now turn to the question of engineering, environment, and economics. In an inertial fusion power plant, the reactor chamber itself would be relatively simple. The inner wall of the vessel can be protected from the hot, energetic fusion products by a flowing layer of some fluid such as molten lithium, a lithium compound, or even ceramic granules. This protection scheme is unique to inertial fusion, and leads to very low radioactivation. The high technology parts of the power plant -- the driver (accelerator or laser) and the factory that produces the targets -- can be located well away from the thermonuclear energy bursts. Because of the relative simplicity of the reactor and the separability of reactor, target factory, and driver, inertial fusion may make good engineering and economic sense.

In the near term, driver research is more urgent than target factory or reactor research. For engineering and economic feasibility it is necessary to develop a reliable, efficient driver having a high pulse repetition rate (several per second) and long life (about thirty years). The drivers constructed by Defense Programs -- lasers and light ion accelerators -- are excellent for near-term research, but they have been designed for low repetition rate, typically a few shots per day. Therefore development of new drivers is needed for power production. During the last decade nearly all high-level DOE and Congressionally mandated committees have identified heavy ion accelerators as the most promising drivers for power production. These accelerators, designed to accelerate ions such as xenon or mercury, are similar in many respects to the large, high energy accelerators that are used worldwide for basic physics research. Indeed many of the requirements of inertial fusion have been demonstrated in existing accelerators. In particular, these accelerators usually have excellent reliability and long life. The new requirement for fusion is the production of

very high instantaneous beam power, greater than 100 trillion watts, while maintaining focusability adequate to hit small targets. There are two main methods of acceleration, induction acceleration and radio frequency (r.f.) acceleration. The r.f. approach is being studied in Europe and elsewhere. We work closely with our foreign colleagues, but we have chosen to develop the induction approach in the U.S.

To establish an experimental scientific basis for induction accelerators in this new high power regime, we have proposed a series of experiments known as the Induction Linac Systems Experiments or ILSE. In 1988 the ILSE Program was reviewed by a DOE committee chaired by James Leiss, former head of the Office of High Energy and Nuclear Physics. It was also reviewed by a JASON panel. Both groups endorsed the ILSE Program; however, the Program was placed on hold by DOE pending the outcome of the National Academy of Sciences (NAS)[2] and Fusion Policy Advisory Committee (FPAC) reviews. The reviews have now been completed and both have given the Program excellent marks.

One issue addressed by the review groups was the location of Heavy Ion Fusion Accelerator Research (HIFAR) in the Department of Energy. It has resided for several years in Basic Energy Sciences, but it has always been recognized that this is not a proper home for a fusion program. Both the NAS Panel and FPAC recommended transfer of HIFAR to the Office of Fusion Energy. This move will occur in FY92.

FPAC recommended two possible funding levels for IFE. Both include the ILSE Program. We have received guidance from DOE to plan to the lower funding level, delayed by one year. The lower funding level recommended by FPAC is given in Table I. The DOE budget for FY92 contains $9.0M for IFE which includes $1.85M for ILSE design. This funding will enable us to ramp into the FPAC funding level beginning in FY93.

Our long-term plans are consistent with the new National Energy Strategy, that calls for an operating demonstration plant by about 2025. To meet this goal we believe that an intermediate facility is required between the ILSE experiments and a full-scale energy driver. Successful completion of an intermediate facility would put us in a position to build an energy driver early in

TABLE 1

Cost of the proposed IFE Program in millions of FY90 dollars (from FPAC Report[1])

Year	91	92	93	94	95	96
Heavy Ion Driver	6	10	16	20	20	20
Heavy Ion Technology		3	5	6	6	6
Materials		2	2	2	2	2
Reactors, Targets		4	4	4	4	4
Total Cost	6	19	27	32	32	32

the next century. Such a driver would be an extremely versatile research and engineering development tool. It would have a pulse repetition rate high enough to serve several experimental areas at once. See Fig. 1. One area could be devoted to target development, other areas could be devoted to reactor development, and still others could be used for applications such as production of various isotopes. Target yield and pulse repetition rate can be varied over a wide range. In particular the target yield can be arbitrarily low and therefore easy to contain. Thus, a variety of small, relatively inexpensive, tritium-self-sufficient reactors could be tested. Since the accelerator would have an ample pulse repetition rate it could serve as the driver for experiments through and including a prototype power plant. Thus, inertial fusion offers an attractive development path.

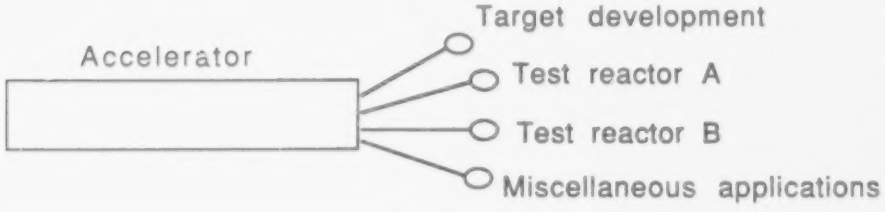


Fig. 1. Schematic illustrating the versatility of a heavy ion driver facility

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In summary, heavy ion fusion is a promising fusion energy option. The next step, the ILSE Program, has been favorably reviewed by four committees. I believe that the heavy ion fusion program is a sound scientific endeavor. With your support we anticipate success. I would be happy to answer any questions.

References

1. Fusion Policy Advisory Committee, Final Report, U.S. Department of Energy Report DOE/S-0081, September 1990.

2. Review of the Department of Energy's Inertial Confinement Fusion Program (September 1990), copies of this report are available from Naval Studies Board, National Research Council, 2101 Constitution Avenue, Washington, D.C. 20418.

Mrs. LLOYD. Thank you, Dr. Bangerter.
Dr. Overskei?

STATEMENT OF DR. DAVID O. OVERSKEI, SENIOR VICE PRESIDENT, FUSION GROUP, GENERAL ATOMICS, SAN DIEGO, CA

Dr. OVERSKEI. Madam Chairman and members of the committee, I thank you for this opportunity to testify before you today. I've already submitted written testimony, and I've requested that be included in the record.

Mrs. LLOYD. Without objection it will be.

Dr. OVERSKEI. Thank you. With that I will take this opportunity to expand on a few other points that were not included in as much detail in the written testimony, and address an issue I think is increasingly important with the future of the U.S. Magnetic Fusion Program and is also, I think, an element necessary for the successful implementation of the National Energy Strategy with regards to fusion, and that is the significant inclusion of U.S. industry.

I'd like to point out, first of all, a little bit about GA (General Atomics) and why we're involved in fusion. Our company was started in about 1955 for the purpose of investigating and developing peaceful uses of atomic energy. Some of you may know of our company because of our development in the gas-cooled reactor, a fission system. But we have transferred a lot of that technology into our fusion program, and we started doing fusion work in the early 1960s.

This work has been through internal funds. It's been funded through the Department of Energy and it's preceding agencies. And we also do contract R&D, and we provide and sell components to a variety of other programs, both in the U.S. and abroad.

I'm very pleased to say that a lot of the technology that the U.S. Fusion Program has paid for and has developed at General Atomics has not only been applied to the U.S. Fusion Program, but has allowed us to help through selling components to the fusion programs; specifically, in Jet and programs in Germany and in programs in Japan.

Now, one of the elements that is very critical in the National Energy Strategy that has been proposed by the Department of Energy is the implementation and construction of several new facilities. Now the reason that this fusion program is ready to begin considering the construction of new facilities is related to the progress that the U.S. magnetic fusion, and, indeed, the international fusion program has enjoyed over the last several years. A number of the preceding speakers have already indicated some of the progress and my own testimony cites some of the numbers. But I would like to just point out that this rate of progress is quite comparable to that we have seen and experienced in the supercomputing industry. The fact that we have had this progress has been largely due to the continuing support of this committee and to the sincere desire to accomplish the objectives of fusion, to demonstrate controlled fusion power, by the individuals that are actively working in the program.

Now, as we have made this significant progress, we stand on the threshold where the last sort of hurdle is this real demonstration

of a sustained controlled fusion reaction. I would like to point out, because we probably have not made it clear, that the experiments that operate today do have fusion reactions and they are controlled and they are sustained. The thing is we don't have a self-sustained fusion reaction, and that's what we're driving and striving for, because that is what will allow us to produce long-term energy.

We need to have new facilities because the information that was applied and the technologies and theories that were applied to produce and fabricate the existing facilities were theories and understandings that we had 15 and 20 years ago, and that has carried us to this point. To go forward, we need to apply the theory, the understanding, the technology of today. And that is how we will be able to demonstrate our controlled sustained fusion. This is not at all different from other sort of breakthrough or state-of-the-art leading technologies. For example, if you look back at the heyday of jets and trying to break the sound barrier, they did not take a prop-driven airframe and put jet engines on it and expect to break the sound barrier. You have to change the entire airframe structure. Again, when you make a threshold quantum jump in computers, you don't take an old mainframe and add a few new chips and say you've got a new generation computer. And our counterparts in the high energy physics program have recognized and have been very successful in identifying the fact that you've reached certain limitations of the facilities, and to address the new uncertainties, to look for the top quark you need new high energies and those energies cannot be attained in the existing facilities. So we must proceed forward.

Now a critical element in the National Energy Strategy is the ITER, and this ITER program would be the demonstration of the Engineering Test Reactor and the integration of the nuclear technologies. This would be a prime role and a prime opportunity for involving industry. Now I would like to point out how I would think you could implement such a process and what some of the benefits would be.

First of all, the U.S. industry has many capabilities, but these capabilities are not at all being utilized by the fusion program at present. It is because we have this difficulty of making the transition from the national labs and the universities that already have facilities and getting more people involved without removing those people that are already participating in the program.

The second element is that if we were to couple our national labs and universities and industries through a process where you would have teams, and the teams being lead by industries, it would have several benefits. The first would be a lot of the breakthroughs in technology that are directly fusion related could more quickly be put into practice because with the active participation of industry you would be able to have a technology or a component that could actually be fabricated and applied.

Thirdly, there would be spin-offs. One of the significant things about fusion is spin-offs. And, if the Chairman would allow, I have a document here that itemizes the number of spin-offs that have come out of the U.S. fusion program, and I would like this to be included in the record.

Mrs. LLOYD. Without objection, we'd be happy to have that in the record.

Dr. OVERSKEI. Thank you. These spin-offs have had enormous impact. For example—and I would just point out a couple of General Atomics' alone—we've developed some high powered conversion systems. These have been used to control the electromagnets that allow us to control and shape plasmas. Now we have sold these systems. We developed them for our own uses; we now sell these systems to other fusion program. And lo and behold, we have found that our technology is the best in the world; it is about a factor of two to five better than the state-of-the-art mass transit technology. We are now building power conversion systems for mass transit systems using this technology. Magnetic resonance imaging systems, which are the best medical diagnostic that's been developed, it is the biggest breakthrough since x-rays for medicine. Well, the people that are building these magnets and selling these systems were trained in superconducting magnets by doing work for the U.S. fusion program. General Dynamics and Westinghouse, who are building the superconducting magnets for the SSC, learned how to do this by doing work on large coil project and on the MFTF–B all funded by the U.S. fusion program. So if you have these teams, you are going to have more tech transfer immediately, and these industries have a lot of desire to get these technologies spun-off into areas that help mankind and society in general.

Now, the other aspect about the coupling of the teams is that as fusion becomes a more international effort, the Japanese and the Europeans already have significant industrial involvement. In Japan, I think it is approximately 80 percent of their fusion program is conducted by industry. The national labs just direct them. It is like a conductor and an orchestra; the national labs are the conductor, and the orchestra is the industries. And I would propose that if we are going to be successful in this international competition, and if we are going to get this technology for the benefit of the U.S.; then, again, you could do so best by having the U.S. industry leaders in the team with national labs and universities coupled, and now the U.S. industries are the representatives in the international forum. This will allow the industries to quickly determine which technologies the Europeans and the Japanese have that can be brought in and can be utilized by our own fusion program and perfected by industry.

Also, I'm sure you know, industries are very covetous of their know-how and their proprietary information, and they will be the best keepers of the information to make sure that things that shouldn't get transferred the other way don't. So I would assure you that if we had these teams, you would maximize your own U.S. fusion program, you would maximize the benefit that you'd get from international participation, and you would maximize the success and the possibility of realizing the objective of a sustained controlled thermonuclear reaction in a device like an ITER.

Now the last point that I wanted to make is about the U.S. fusion program, specifically. We strongly endorse the Department's 1992 budget that was submitted. This budget includes support for ITER, which we feel very strongly about, and it also includes some design work for BPX, which we feel out of all the supporting pro-

grams in support of the ITER concept, the BPX should be given the highest priority.

With that, I thank you for your attention.

[The prepared statement of Dr. Overskei and referenced document follow:]

Statement for the Record
FY-92 DOE Authorization
Magnetic Fusion Energy Program

Subcommitee on Energy Research and Development
Committee on Science, Space and Technology
U.S. House of Representatives

Dr. David Overskei
Sr. Vice President
General Atomics

March 13, 1991

I am David O. Overskei, Senior Vice President of the Fusion Group at General Atomics in San Diego, California. Madam Chairman, thank you for the opportunity to appear before you today and offer my testimony concerning the U.S. Magnetic Fusion Energy research program.

General Atomics is the largest industrial participant in the U.S. fusion research program. Of our approximately 1,500 employees, over 225 scientific, engineering, and support personnel work directly on fusion activities. Under contract to the Department of Energy we designed, constructed, and now operate the DIII-D, a U.S./Japan collaboration, which is the second largest tokamak facility in the U.S. Based on our performance and results we feel that DIII-D may also be the most flexible and productive tokamak in the world. Our other fusion activities include fusion component engineering and fabrication theory, applied plasma physics, experimentation, and fusion technology development. A hallmark of our fusion activities is our extensive collaboration with five national laboratories, 13 universities, and multiple European, Soviet, and Japanese programs. In addition to our contracted work for the Department of Energy, we perform research and sell fusion components and materials to many of the fusion research laboratories and universities in the U.S., Europe, and Japan.

Today I want to discuss four items: GA's interest in fusion, the status of magnetic fusion research, the future U.S. magnetic fusion program, and the role for industry.

GA's Interest In Fusion

Since its inception in 1955, General Atomics has had an abiding interest in the development of atomic energy. We feel that the fusion process, which produces no radioactive waste from the reaction, uses a readily available and abundant supply of fuel, and is passively safe, holds the promise of being the ultimate long-term energy source for mankind. Our objective is to participate in the commercialization of fusion power.

In addition to the development of a new energy source, fusion research allows us to contribute to society through state-of-the-art research at the frontiers of science and technology development. This research has resulted in many spin-offs that have enhanced U.S. competitiveness and improved the well being of U.S. facilities. I request that a list of such fusion spin-offs, which I have attached to the end of my statement, be included in the record. I would like to mention a few of these spin-offs which have come from GA.

1. The San Diego Supercomputer Center, operated by the National Science Foundation, is the most productive of the four centers in the U.S. This center was started by personnel who came from the GA Fusion Division, and who acquired their expertise while conducting fusion research for the U.S. Department of Energy.

2. GA is a leader in the design and development of electromagnetic launchers for Department of Defense programs. This expertise is a derivative from our electromechanical engineering requirements for fusion energy programs.

3. Drawing upon our fusion generated superconducting magnet expertise, General Atomics became one of the main OEM providers of superconducting magnets for commercial magnetic resonance imaging systems, perhaps the most significant medical diagnostic breakthrough since the development of X-rays.

4. Our fusion expertise in shaping plasma led to the development of power conditioning technology that is unique in the world. We have sold systems to MIT and are now applying this technology to light rail mass transit cars.

Status of Magnetic Fusion Research Program

Since the Soviet invention of the tokamak in the early 60s, there has been enormous and rapid progress in the development of the magnetic fusion concept. In fact, since 1970 the plasma performance demonstrated in tokamaks has doubled every two years. This is a rate of progress comparable to that in the supercomputing industry. Let me cite several examples: Since 1989 the value of beta, which is the ratio of reacting plasma pressure to the confining magnetic field pressure, has gone from just under 7% to approximately 11% on the DIII-D device. A value of 5% has been considered a minimum for a fusion reactor. The time period in which we can sustain a high temperature fusion plasma has gone from approximately 3 seconds to up to 10 seconds on the DIII-D device. The reacting plasma temperatures demonstrated on the TFTR at Princeton University has gone from 300 million degrees to now in excess of 400 million degrees.

In parallel with these significant and important plasma parameter demonstrations, we have also increased our understanding of the fusion plasma. The theories allowing us to predict the control and the shape of a reacting fusion plasma have now been verified by the experimental results and measurements attained on the DIII-D and other devices throughout the world.

To sustain this progress, we must continue operation of our primary tokamak facilities. The present facilities not only represent an enormous investment, but they are producing results that continue to advance the state-of-the-art. However, upgraded performance of these machines through the addition of new heating and diagnostic systems is required to verify the new theoretical physics models and confirm theory predictions. This approach, which represents a fraction of the original facility capital costs, will allow us to realize the full potential of the present experimental facilities, maximizing the return on the significant investment of taxpayers' money.

The Future U.S. Magnetic Fusion Program

We strongly support the Department of Energy's budget submitted for fiscal year 1992. We concur with the Secretary's decision to make the transition from a fusion research program to a fusion energy development program with a high level of science and technology development. Other magnetic confinement concepts have contributed significantly to the science and the understanding of the magnetic fusion process. However, the impressive progress demonstrated by the tokamak confirms that focussing on the tokamak and continuing improvements of the tokamak concept is the correct choice if we are to meet

the objective of an operating fusion power plant by the 2025 and operating commercial fusion power plant by the year 2040.

Based on today's demonstrated results, we are now at 10% of the conditions necessary for a sustained fusion reaction. We can say with certainty that the remaining 90% can be achieved based on our present knowledge and technology. However, none of the present operating fusion facilities in the world are capable of achieving a self sustained fusion reaction. These facilities were designed using theories and technologies that were in existence as long as 15 to 20 years ago. It is evident that we need to incorporate today's technology and understanding through upgrades of present devices or new facilities if we are to demonstrate a sustained controlled thermonuclear fusion reaction. This requirement to invest in new facilities to accomplish such a demonstration is not peculiar to fusion but, in fact, is the norm in breakthrough technology and science programs.

In the National Energy Strategy recently released, the Department of Energy identified four new magnetic fusion facilities that would be necessary to meet the objectives of the magnetic fusion energy development strategy. The first is an engineering test reactor, embodied by the International Thermonuclear Experimental reactor (ITER) which is an international program including the Soviet Union, European Community, Japan, and the United States. The purpose is to demonstrate the scientific and technological feasibility of fusion power using a tokamak.

The project has four phases, Conceptual Design Activity, Engineering Design Activity, construction, and operation. The first phase, the Conceptual Design Activity begun in 1988, has already been successfully completed. The U.S. has entered negotiations on the Engineering Design Activity, the second phase, which is to last six years. During this phase the four parties will equally support the detailed engineering design, the R&D, prototype fabrication, and testing of components for the ITER device with the total expenditures expected to be on the order of one billion dollars. At present the U.S. is negotiating with the four parties to determine the location of the Engineering Design Activity. The proposed U.S. site is San Diego in competition with Naka in Japan and Garching in Germany.

The U.S. should aggressively pursue and embrace the ITER process. This process poses a unique opportunity for the U.S. Magnetic Fusion Program and the country as a whole. Historically, the U.S. has provided the leadership in both the science and the technology of fusion research. However, owing to a variety of circumstances, budget reductions in the U.S. and aggressive program development on the part of the Europeans and Japanese, each of the parties brings unique strengths of comparable value to the program. By all indications the U.S. is still leading in the scientific area, but the Europeans and Japanese are at lease on a par, and in many areas are now ahead of the U.S. in the development of critical and long term fusion technologies. We encourage the Congress to support the U.S. participation in this activity and to support the Department of Energy in its efforts to locate the Engineering Design Activity in the United States. Doing so will allow more U.S. participation in the Engineering Design Activity and will facilitate the transfer of fusion technology from the European, Soviet, and Japanese programs into the U.S. fusion program.

There are three other program elements cited as necessary in the Fusion Energy Development Strategy. These are: (1) the Burning Plasma Experiment -- to investigate the physics of self-heated fusion plasmas and to demonstrate the production of 100-500 MW of fusion power, (2) the Steady State tokamak--to develop and test technologies that are necessary for steady-state operation of a tokamak reactor system, and (3) a Materials Test Facility--to develop and test low activation materials that would be necessary for a fusion power reactor. We feel that at least one of the above three programs should be initiated in support of the U.S. participation in the ITER process with the BPX given the highest priority. In doing so, the U.S. will maintain an active and ongoing fusion development program while realizing the benefits of international cost sharing and technology development that would be associated with participation in the ITER.

The Role for U.S. Industry

Until recently, the U.S. Magnetic Fusion Research program was dominated by the science of plasma physics. The larger and more sophisticated devices that we now need to demonstrate fusion power must also incorporate new technologies and skills, such as project management, quality control, and very large scale manufacturing and machining with new state-of-the-art materials. This can best be done with a much larger participation on the part of U.S. industry. Japan realized this years ago and already has in place a very active industrial participation in its fusion programs. The Japanese national laboratories direct their work, and the industries perform the design, engineering, fabrication, and much of the operation of the major facilities in the Japanese fusion program.

I propose that we learn from the approach pioneered by the Japanese. In the future all major device design, engineering , facility construction, and operation should be carried out by teams of industry, national labs, and universities led by the industrial partners. GA has effectively implemented such a process with the DIII-D. Such an arrangement will have many benefits:

1. Our prestigious universities and national labs, which constitute valuable national resources will continue to provide innovation and breakthroughs. Because the universities and national labs are more tightly coupled to industry, their innovation will more likely be one that is carried though to practice.

2. Competition through multiple teams will ensure that multiple approaches are generated and the best ideas prevail.

3. Having an industry involved in all phases of the science and technology development will facilitate technology transfer to industry such that society can more rapidly and effectively benefit from the potential spin-offs.

4. We will have established a fusion industry capability whereby a national fusion economy could be realized once the technical problems are resolved.

In particular, ITER offers an occasion to make this transition to industry-led teams. The next phase, the Engineering Design Activity will include significant amounts of R&D and prototype fabrication ideally suited for performance by industry in a lead role with national labs and universities as teaming members. Not only will we accomplish technology transfer from our own national labs to our own industries, it will optimize the transfer of technology that exists in the European and Japanese programs to our own U.S. industries. This in turn would position the U.S. industries on an equal footing with their international industrial competitors, thereby enhancing our ability to effectively compete on the major engineering design and fabrication components for ITER and subsequent demonstration reactors to be developed in the U.S. or abroad.

In closing, the U.S. Magnetic Fusion Program is a premier example of state-of-the-art science and research, meeting one of the finest but most difficult challenges upon which man has ever embarked. With the next generation of devices now under consideration, we will be capable of demonstrating a controlled sustained thermonuclear burn--a small star generated by man's intellect for the benefit of all mankind. We stand here today because of your past support. With your continued support, we can together realize the dream of controlled fusion power.

Mrs. LLOYD. Well, thank you. Great testimony.

Mr. Brown?

Mr. BROWN. Thank you very much, Madam Chairman.

Let me just draw on the last point that you've been making, Dr. Overskei. I was struck when I read your testimony, and even more as you amplify on it, we have a problem here resulting from the different culture, I guess you would say, and by that I am referring to the way in which our labs and research universities relate to industry from that of the Japanese. As you point out, 80 percent of their work is done by industry, lead by industry. It is not well known in this country, it is not the Japanese Government that does all this great R&D that leads to their taking our markets, it is the industry that finances the R&D and then develops the commercial applications of it. How do we go about changing that? You've suggested that ITER is a test bed not only for the fusion reactor but for a new mode of relationships. What could we do as a committee to encourage that on the part of the Department of Energy? What needs to be done that will move us in this direction?

Dr. OVERSKEI. Well, very specifically, I would propose that any time the Department is considering any new initiative, they accept proposals not from the national labs directly, but only from industry, lab, and university teams.

I can understand where you have an existing operating facility, then you should sustain that whether it be at the university or the national lab. That would be somewhat foolish to remove that. But anything that is new and over and above the operating costs for the present facility, I would recommend that the Department say that we will consider only proposals that come in from teams.

Mr. BROWN. Well, we'll have to consult with the Department and see how much of a trauma that would produce over there. [Laughter.]

I am inclined to feel that you are correct. One of the things that distinguishes fusion, however, from other long-range research programs—and you have suggested some of them—is that in most of these others there are obvious commercial benefits that flow from that activity even as it moves along the path toward its ultimate goal. And that hasn't been quite so clear in fusion, although it probably should be. We might probably should have been exploiting some of the things that you mentioned, such as the high powered magnets and the power conversion and so forth, to indicate the value of the on-going research even though it hasn't culminated in an operating power plant yet. That kind of exploitation, if I may use the term, could best be done by industry because there is something about the culture of industry that tends to look at an on-going program from the standpoint of what immediate societal values are we getting out of it. That could produce a major enhancement in public support again for the long-term fusion program.

I know that my remarks indicate that I'm looking at this in a crass, non-scientific way, but I am trying to combine the two actually to make sure that we achieve the goals that we have in mind. This is not a question, but obviously if we succeed in this new culture for fusion, it will make it easier to do it in some of the other

areas where we're currently grappling to overcome the Japanese leadership in the development of advanced technologies.

Madam Chairman, having gotten that off my chest, I think I'll——

Mrs. LLOYD. Thank you very much.

Mr. Schiff?

Mr. SCHIFF. One item. Dr. Davidson, I note that you supervise a plasma physics laboratory. My brother, who I have mentioned before, is a physicist who doesn't know whether to laugh or to cry at the fact that I, a lawyer, am on this committee. More particularly, my brother is a plasma physicist. I want to share with you a true story. He once got the flu and was treated by a medical doctor, they were chatting and the doctor said, What do you do? My brother said, I'm a plasma physicist. The medical doctor didn't charge him; he felt my brother was a blood specialist. And I kind of wondered, does that happen frequently to plasma physicists? [Laughter.]

Dr. DAVIDSON. Occasionally, it does.

Mr. SCHIFF. Okay, let me say seriously, Madam Chair, I think this was outstanding testimony. I really have no questions that I can think of to follow up with it. I appreciate it very much.

Mrs. LLOYD. And I certainly agree with Mr. Schiff. This has been outstanding testimony this morning. I was sensing something in this room that I haven't experienced in previous years when we've had our fusion hearings. There is an upbeat mood in this room today and I think everyone in the room will share that with me.

You all did just a beautiful job. Dr. Davidson, we're all excited about the tritium experiments certainly at Princeton. The subject was brought up in previous years on the acceptance of moving to this stage. Are there any hurdles in the environmental process going ahead at Princeton?

Dr. DAVIDSON. Let me just comment with regard to TFTR, the environmental assessment documentation has been submitted to the Department of Energy this month and that it is evaluated by the Chicago Operations Office, the Office of Energy Research, and eventually the ES&H division of the Department of Energy. That's about a three-month process, so we expect approval for the EA sometime in June.

I would comment locally that we have extensive briefings and information discussions with the New Jersey Environmental Protection Agency, with local chambers of commerce, local environmental planning boards, and we certainly see no technical or environmental——

Mrs. LLOYD. You see no major impediments. Very good. That's very good news.

You commented that if the BPX-Tokamak facility were built, there should be an environmental review. Looking at our budget, as you know, we haven't had any construction funds in the past 15 years. When do you think BPX will be ready for project status?

Dr. DAVIDSON. I believe it will be ready for project status in the sense of request for construction funds in fiscal year 1993.

Mrs. LLOYD. As a line item?

Dr. DAVIDSON. As a line item, yes, ma'am.

Mrs. LLOYD. Very good. That's good news.

Dr. Parker, you mention spin-offs and the magnetic fields, and we're also talking about spin-offs and the efforts to really spotlight some of these efforts. I would like for you to be a little bit more specific on the possible applications in other areas of research and our large scale superconducting magnets. Would one be in the transportation field?

Dr. PARKER. Yes, I of course didn't have time to go into any detail. I mentioned several areas, including propulsion using MHD conversion. We're working in my lab on the SSC magnets, as a matter of fact.

Mrs. LLOYD. You have all the time you want now to talk about it.

Dr. PARKER. I don't think you'd want to listen to all I have to say. [Laughter.]

So we're working on SSC magnets and detector magnets, for example, in my laboratory. Magnetic levitation for transportation is an idea that's been around for a long time. Many people think perhaps it is an idea whose time may have once again come; we certainly hope so. That is another application. We are looking now at ways of capitalizing on the new technology from Hi-TC superconductors to build practical magnets, and that's being looked at in my fusion laboratory at MIT. And was mentioned by Dr. Overskei, magnetic resonance imaging, certainly one of the most visible-to-the-public uses of advanced magnet technology. So these are all technology areas that are unified by the use of very high—well, difficult to design anyway—magnet systems, and they are all spinning-off from the work that we're doing at least in my laboratory in connection with magnetic fusion design. And that is being amplified now in connection with the ITER process, so there is a spin-off directly coming from the ITER activities.

I would like to mention, Madam Chairman, that by no means is magnets the only spin-off area. Of course, fusion, one area particularly that we're developing now, finding a great deal of response to, is the use of plasmas—in this case, not high temperature in the sense of fusion plasmas but high temperature in the sense of what temperatures can be reached in gaseous situations—use of those plasmas for waste processing and disposal. As you know, the waste area is one of increasing concern to society, certainly to the Department. And what we're looking at and working on right now is we have an initiative to use plasma, use our technology that we're developing and learning about in the fusion area, to the problem of waste disposal, waste remediation. So this is an exciting new area actually for transferral of knowledge and technology out of the plasma area to another completely different area of technology.

Mrs. LLOYD. Thank you very much.

Dr. Bangerter, you said in your testimony that important areas now in the fusion programs are in the engineering area; is that correct?

Dr. BANGERTER. Yes.

Mrs. LLOYD. In this context, which approach to acceleration do you feel is simpler or more advantageous for a future demonstration facility?

Dr. BANGERTER. Well, there are two main approaches to heavy ion fusion—the radio frequency accelerator approach and the induction accelerator approach. We believe that the induction accel-

erator approach is simpler and we have chosen to develop that in this country.

Mrs. LLOYD. Why?

Dr. BANGERTER. It looks like it is simpler; it looks like it is cheaper.

Mrs. LLOYD. That's two good reasons.

Dr. BANGERTER. Those are two good reasons. Our colleagues in Europe are developing the radio frequency approach and we think that—we work closely with our colleagues, we're on top of that situation, but we have chosen the induction approach for the two reasons that I mentioned.

Incidentally, in addition to my oral testimony, I have also prepared written testimony and I request that be entered into the record.

Mrs. LLOYD. Without objection, it certainly will be. Thank you.

Dr. Overskei, you asked permission to put the spin-offs that you have achieved in the record. We not only want them in there, I think that this is an area where we need to spotlight our achievements. As everyone in this room involved in the industry knows, one of our major problems has been the fact that fusion program, being a long-term program, is something that is perhaps in the minds of some Members of Congress that we might put on the back burner. I think that there is no better year—and I say this to all of the panelists—to be talking about the spin-offs to gender more public support for our program. And not only is it good business, it certainly makes good political sense as well. So I would encourage all of you to bring to the light the diverse applications of the great work that you're doing. And I also want to congratulate you on your progress.

Do you think perhaps this success story might be used as a model for other technologies as well look toward tech transfer?

Dr. OVERSKEI. In what—how do you mean?

Mrs. LLOYD. Well, obviously, you're doing a good job with technology transfer.

Dr. OVERSKEI. Yes.

Mrs. LLOYD. And do you think this could be a model for other programs as well?

Dr. OVERSKEI. I would say that we could do a little bit more with tech transfer. We have a lot of things that we have done and developed already, but I believe that we could do a little bit more in the tech transfer area. One of the reasons that makes it somewhat difficult is that a lot of the programs that get started and developed in these long-term areas, the research gets transferred from one technology to another and it just doesn't become visible. And that's probably a deficiency on our part. I think largely speaking we're excellent scientists and relatively poor marketers. You need some marketing such that people know what it is that you're doing and its value.

But I believe everybody is very seriously interested in applying these technologies to other areas. We certainly do it here. I know that a lot of places—well, I'm familiar with MIT and Oak Ridge, who I know have very extensive efforts in trying to do tech transfer of fusion things into other areas and to outside companies, and I know Livermore has an active program as well.

Mrs. LLOYD. You are all very good scientists, but I also want you to be very good businessmen so we can keep on paying for this program. [Laughter.]

Is it more difficult when you are looking at a program where some of the pay off will be maybe six decades away to get the public participation?

Dr. OVERSKEI. Yes, it certainly is.

Mrs. LLOYD. Do you think Stevenson-Widler Technology Transfer Act will be of use here?

Dr. OVERSKEI. Well, I believe it will. To a certain extent, it depends upon how it actually gets implemented. And the other question here is, again, whether or not we show sort of linkage and make that public so that people realize where the technologies were derived.

Mrs. LLOYD. Well, thank you very much, gentlemen. We appreciate your testimony. Oh, wait a minute. Pardon me. Mr. Smith is here.

Mr. SMITH. Thank you, Madam Chair. I sneaked in a couple of minutes ago and would like to ask a couple of questions, if I may.

Mrs. LLOYD. We're delighted you're here.

Mr. SMITH. Thank you. Dr. Davidson, first question for you. If the BPX is not built, what strategy do you think the United States would be forced to adopt?

Dr. DAVIDSON. While you were out of the room there was a very eloquent statement by my colleague here, Dr. Ron Parker, as to the reason that both the ITER facility, which is predominantly an engineering test reactor facility which would precede a demo, as well as the Burning Plasma Experiment, which is more of a physics oriented experiment; both are required for the national and international development of fusion energy.

So I would answer your question by repeating that the BPX step is a very important step in the fusion program to avoid costly mistakes in ITER. There are items related to the internal hardware in the machine, and the operation of the divertor under high heat flux conditions. There are various external subsystems related to remote maintenance, learning to control fusion plasmas under conditions in which there is significant alpha particle self-heating, learning operating scenarios that would be of great value to the ITER project and allow it to emphasize the engineering aspect of its mission.

Mr. SMITH. Okay. Thank you.

Dr. Parker, one question. I am mindful in asking this question, it reminds me of the kind of questions that politicians like to be asked because if we're asked to make predictions, it gives us an opportunity to talk twice—one is to make the prediction, and the second is to tell you why we were wrong. And I am hoping you are going to be right on this. The National Energy Strategy predicts that it will be something close to 50 years before a commercial reactor can actually come on the line, and then there's various predictions of 25 to 30 years before we even have a demonstration of fusion. What is your prediction? I mean, do you think that those are unduly pessimistic? Do you think that we can have a commercial reactor prior to 50 years from now?

Dr. PARKER. Well, you have to differentiate producing a commercial reactor versus producing a measurable amount, let's say, of usable power. I think that th ——

Mr. SMITH. I'm talking about measurable amounts.

Dr. PARKER. Yes. Then I think 50 years is unfortunately a realistic estimate for producing significant power by fusion. I don't personally see a way of doing it before then. Let me just say, if you're looking at any large scale technology, such as required for the utility industry, I really don't think it will matter too much what particular technology, I believe you are looking at 30 years before you are going to see substantial impact in terms of the 300 or so gigawatt capacity that we currently consume.

It is the nature of these systems. If you took an example from a new generation of fission reactor, for example, you would imagine 10 years to build some sort of prototype, several years for the utilities to kick the tires and the public to react to it, and then another 10 years to build the first—just the first—model or the first few models. So you add those years up, and that's perhaps 25 to 30 years. It is always disappointing to think in terms of that time frame, but it would be irresponsible, in my view, to make a prediction that we could significantly change or shorten that time.

Mr. SMITH. I appreciate your candid answer. Thank you, Madam Chair.

Mrs. LLOYD. Thank you very much. Thank you gentlemen.

The second panel today consists of Dr. Harold Forsen, Vice President of R&D at Bechtel Power Corporation; Dr. Stephen Dean, President, Fusion Power Associates; and Dr. Alex Glass, Associate Director for Programs at Lawrence Livermore National Laboratory.

Dr. Forsen, you may begin.

STATEMENT OF DR. HAROLD K. FORSEN, SENIOR VICE PRESIDENT AND MANAGER, RESEARCH AND DEVELOPMENT, BECHTEL CORP., SAN FRANCISCO, CA

Dr. FORSEN. Thank you Madam Chairman. It is a pleasure to be here and offer my testimony regarding the future energy needs of our country and the important role that fusion could play in providing a clean safe source of energy. I was the chairman of the Magnetic Fusion Subcommittee of Fusion Policy Advisory Committee [FPAC], which recently presented its report to the Secretary of Energy. It is relevant to review the policy recommendations made to the Secretary of Energy which have now become part of the National Energy Strategy.

First, FPAC determined that the magnetic fusion program is technically ready to move from a science based program to take on the additional elements of a more focused energy research program and to address the challenges of fusion engineering.

Second, FPAC recommended that we should make every effort to both move the program forward, and preserve national resources by participating to the fullest extent possible in international collaboration; specifically, the pending International Thermonuclear Experimental Reactor [ITER]. This is to be an experimental test reactor to demonstrate the engineering aspects of fusion. Such an ac-

tivity provides a unique opportunity to bring industry into a meaningful role in the U.S. program, and to begin the task of technology transfer. We need to assure that over the longer term the program will see the development of a competitive U.S. industry which will design, fabricate, and guarantee the performance of these power systems. Let me come back to that later.

In order to assure the position of the U.S. program as an equal partner in international collaboration, we must have a strong domestic program. This led the committee to recommend two elements: One, that the base program be strengthened to take better advantage of facilities under construction and in initial operation. This is to help assure that the reactor which ultimately emerges is the best it can be. You all know that because of budget cuts in conference last year, the Program Office had to cancel several important complementary activities.

Two, to maintain a rational domestic program and to push the technology that was most advanced, the Tokamak, we recommended that a Burning Plasma Experiment [BPX], a successor to the Compact Ignition Tokamak [CIT], be constructed as rapidly as possible. This essential new burning plasma phase of the program appeared to us to better position the U.S. in the international arena, establish the U.S. as a strong and equal partner to ITER, and to better assure the start-up and early operation of ITER itself.

Because of the budget cuts already mentioned, I, and others on the committee, supported strongly those steps the Office of Fusion Energy had to make in reducing a concept improvement program to protect the ITER initiative and the continued design of the Burning Plasma Experiment. The current 1992 proposed budget permits these key elements to proceed but at a reduced pace never really anticipated by our committee. Nevertheless, competitive progress can be made with this budget so long as a construction line item for BPX begins in fiscal year 1993, and the ITER Engineering Design Activity proceeds as planned now.

Let me return to ITER as an opportunity for technology transfer to industry and an opportunity for industry to bring its experience to bear on this important international design. The FPAC strongly recommended that a more formal program be established to bring appropriate industry into the fusion program for the long-term and to begin to develop a competitive U.S. industry base to compete with the more aggressive industrial programs in Japan and Europe. New funds for ITER can well be used to assist in transferring technology and bringing industry into the program as a full partner. This will add to the program costs, but will reduce the cost longer-term as the private sector begins to take a greater interest and makes its contribution to the fusion power program.

This cannot happen under the current budget or circumstances. Future budgets must anticipate this need and this opportunity, and the Program Office must formalize its commitment to industrial participation. Fusion has an important role to play in the longer energy mix of our society. It is now time to begin the real scientific and engineering proofs and demonstrate its performance.

Thank you.

[The prepared statement of Dr. Forsen follows:]

STATEMENT OF

DR. HAROLD K. FORSEN
SENIOR VICE PRESIDENT, BECHTEL CORPORATION

TO THE
SUBCOMMITTEE ON ENERGY
OF THE
HOUSE COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY

March 13, 1991

Madame Chairman, members of the Committee: Thank you for the opportunity to appear before you today and to offer my testimony regarding the future energy needs of our country and the important role that fusion could play in providing a clean safe source of energy. I am Harold K. Forsen, Senior Vice President and Manager for Research and Development at Bechtel Corporation. I was the chairman of the Magnetic Fusion Subcommittee of the Fusion Policy Advisory Committee (FPAC), which recently presented its report to the Secretary of Energy. It is relevant to review the policy recommendations made to the Secretary of Energy which have now become a part of the National Energy Strategy.

First, FPAC determined that the magnetic fusion program is technically ready to move from a science based program to take on the additional elements of a more focused energy research program and to address the elements of fusion engineering.

Second, FPAC recommended that we should make every effort to both move the program forward, and preserve national resources, by participating to the fullest extent possible in international collaboration; specifically, the pending International Thermonuclear Experimental Reactor (ITER). This is to be an experimental test reactor to demonstrate engineering aspects of fusion. Such an activity provides a unique opportunity to bring industry into a meaningful role in the U.S. program, and begin the task of technology transfer. We need to assure that over the longer term the program will see the development of a competitive U.S. industry which will design, fabricate and guarantee the performance of these power systems. Let me come back to this later.

In order to assure the position of the U.S. program as an equal partner in international collaboration, we must have a strong domestic program. This led the Committee to recommend two elements: One, that the base program be strengthened to take better advantage of facilities under construction and in initial operation. This is to help assure that the reactor which ultimately emerges is the best it can be. You all know that because of budget cuts in Conference last year, the Program Office had to cancel several important complementary activities. Two, to maintain a rational domestic

program and to push the technology that was most advanced, the tokamak, we recommended that a Burning Plasma Experiment (BPX), a successor to the Compact Ignition Tokamak (CIT), be constructed as rapidly as possible. This essential new burning plasma phase of the program appeared to us to better assure the U.S. position in the international arena, establish us as a strong and equal partner to ITER, and better assure the startup and early operation of ITER itself.

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Let me return to ITER as an opportunity for technology transfer to industry and an opportunity for industry to bring its experience to bear on this important international design. The FPAC strongly recommended that a more formal program be established to bring appropriate industry into the fusion program for the long term and to begin to develop a competitive U.S. industry base to compete with the more aggressive industrial programs in Japan and Europe. New funds for ITER can well be used to assist in transferring technology and bringing industry into the program as a full partner. This will add to the program costs, but will reduce the costs, longer term, as the private sector begins to take a greater interest and makes its contribution to the fusion power program. This cannot happen under the current budget or circumstances.

Mrs. LLOYD. Thank you, Dr. Forsen.
Dr. Dean?

STATEMENT OF DR. STEPHEN O. DEAN, PRESIDENT, FUSION POWER ASSOCIATES, GAITHERSBURG, MD

Dr. DEAN. Thank you, Mrs. Lloyd. It is a pleasure to be here.

Mrs. LLOYD. We're happy to see you again today.

Dr. DEAN. Fusion Power Associates was formed 12 years ago to be a public benefit corporation, by which I mean an institution whose primary purpose is to bring the benefits of all this fusion research to the public. The only way that this is can happen is to bridge the gap between the research program and the private applications of fusion technology, which I think requires, as we all recognize, the full participation and interest of the private sector. Consequently, Fusion Power Associates has been primarily sponsored by U.S. industry, both major corporations and many small businesses; but we also include in our association a number of universities, national laboratories, and electric utilities.

As has been mentioned by several people on the first panel—and I was very pleased to see that; we did not coordinate our testimony but I am glad to see that many of us are thinking the same way—that the reality is that the research investment in fusion over the years has already resulted in a number of public benefits through the process of specialized spin-offs that are used in a variety of areas. These have been mentioned by the FPAC; I've indicated some of them in my testimony; and they've also been submitted for the record by Dr. Overskei. So we are very pleased to see that fusion in fact has already been delivering benefits to the public and we don't have to wait this large number of years simply to get an electric power plant to be the first practical benefit from all this research.

The second point I would like to make is that I've been very pleased to see the status accorded to fusion in the National Energy Strategy. This could be taken for granted by many of us as being well deserved, but the reality is that over the years the Department of Energy has not usually accorded fusion such a prestigious position in this long-range planning document. Usually we have been relegated to a fairly small paragraph somewhere under their research activities. Now we are prominently mentioned as a long-range alternative to such major power sources as coal and nuclear power and the renewables. I think this reflects a coming of age, if you will, of both the fusion research program and, also, perhaps a coming of age of the recognition on the part of the Government that in fact fusion is the place where we'd like to wind up in this country for our major baseload power source.

Another point I would like to make—and I've made this many times in the past—is that we cannot get from where are today to where we need to go without new facilities. It has been mentioned earlier by several speakers that it has been 15–16 years since our last major Tokamak construction project, the TFTR, which was in the fiscal year 1976 budget. We're still looking to see when the next machine is going to go in the budget. Dr. Davidson commented to you in response to a question that he hoped it would be in

next year's budget. Well, I remind you that it was in the budget two years ago and that Admiral Watkins, in his "wisdom" at that point, withdrew it from the budget. We have been trying to get it back in the budget ever since.

I remember, as I suspect you remember, that back in 1984 we had a proposal to build a machine called the TFCX, or Tokamak Fusion Core Experiment, which was a similar type of machine. We've been trying to get the successor of TFTR into the budget for many years. The significance of that is that, until we do, the clock will really not start ticking in the next phase of fusion that's going to bridge the gap between the research program and the first demonstration reactor.

Now, unfortunately, during the last decade, the buying power of the fusion budget has gone down by a factor of two. You will remember back in 1980 when we projected some of these budgets, and that the budget at that time needed to go up by a factor of two. So, having lost a factor of two and needing to go up by a factor of two, we're really short by a factor of four in the budget to be on a schedule that would really expeditiously develop fusion on a time schedule that would be paced by the technology rather than by the budget.

I think the FPAC sort of put forth a middle ground. They said let's increase this budget by a factor of two and we'll give you a demonstration reactor in 2025, which is 35 years in the future. I think that's an uncomfortably long time but I think it probably reflects the reality of their feeling that getting a factor of two in this budget is going to be a major undertaking, and I think that is probably correct.

So one of the points I would like to make is that let nobody be under any false illusion that we are now back on track as an energy development program with a schedule, in this budget that's been submitted. We have perhaps arrested the decline if we get this budget. But unless this budget is going to grow, and then along with that we get the construction back rather than just say we're going to continue design and get it next year, unless that happens, we will really not be back on track of being a development program. I think we badly need from the Congress, and I know that you recognize this, an authorization bill to provide guidance and policy deliberations from this side of the House to the Appropriations Committee, so that they will have a clear vision as to why they should appropriate more money for this program.

Mrs. LLOYD. Dr. Dean, I can assure you that there will be an authorization this year.

Dr. DEAN. And we'll support you on that every way we can.

Mrs. LLOYD. The reason we're having two hearings a week is so we can be ready to go to full committee.

Dr. DEAN. I also think there is some evidence that the Congress would like to pass some type of Energy Policy legislation to complement the National Energy Strategy. I noted that you submitted an excellent bill along these lines last session and Senators Johnston and Wallop have submitted a bill recently. I endorse having such legislation. I think it is important to somehow codify the Congress' position on the National Energy Strategy. I hope when that hap-

pens that there will be a fusion title in that legislation that will spell out the Nation's intent with respect to fusion.

In that regard, I would specifically endorse the concept that is in Senator Johnston's bill of establishing some type of a trust fund mechanism to pay for the growth not only in fusion but in other energy technologies. I am very concerned by the fact that the normal appropriations process, which is now sort of capped by the budget agreement of last year, not to grow unless something else gives, is going to create an impossible situation for programs like fusion that need new construction and budget growth. So I am really concerned for future years as to how we can find the money in the appropriations process to pay for not only fusion but a number of other energy technologies, and trust fund type funding I think should be seriously considered. I know that Senator Johnston has a very controversial mechanism for providing money into that, being royalties out of the opening up of the ANWR; but I think other types of levies on electricity production or on fossil fuels could possibly be considered to fund such a trust fund. And I would hope fusion and other energy technologies would be a part of such an activity.

Finally, I would like to note that I am very glad to see Dr. Bangerter here. I have been advocating before this committee several years that we should in fact embark on the Heavy Ion fusion program more vigorously as part of the overall national fusion program. The FPAC has endorsed that; the Department seems to have now endorsed that and transferred the program into the Office of Fusion Energy. I would like to see that program prosper.

And finally, I would like to pick up on what Dr. Parker said about the alternate concepts. I am very disappointed to see the Department last fall terminate basically all the non-Tokamak programs. With all due respect to the great accomplishments to the Tokamak community, I believe that they need an internal critic in the program to hold their feet to the fire, and I believe the alternate concepts program's people effectively did that by pointing out new ideas and new concepts based on research on non-Tokamak programs. I think this is a relatively inexpensive part of the program and I think it is going to be very sorely missed in the future. So I would keep a very close eye on that and bring back some of those programs at the earliest possible time.

Thank you.

[The prepared statement of Dr. Dean follows:]

Fusion Power Associates

STATEMENT OF
DR. STEPHEN O. DEAN
PRESIDENT
FUSION POWER ASSOCIATES
TO THE
SUBCOMMITTEE ON ENERGY
OF THE
HOUSE COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
MARCH 13, 1991

Fusion has an important role to play in our energy future. As the DOE's Fusion Policy Advisory Committee eloquently states: "Fusion is one of very few energy options that offers an essentially inexhaustible and widely available fuel supply . . . . It has the prospect of being relatively benign with respect to both worker and public safety and the production of environmentally objectionable by-products."

The National Energy Strategy (NES) document, recently issued by the DOE, lists fusion, appropriately, in the section on "Securing Future Energy Supplies," along with coal, oil, natural gas, nuclear, and renewable resources. In my reading of the NES document, fusion is used to "anchor" the report in the future, as fossil fuels "anchor" the report in the present. In other words, fusion is where the country is aiming, ultimately, in order to secure its energy future.

According to the NES, fusion could "provide an environmentally acceptable alternative to fossil-fuel combustion, and help ensure continued economic growth through reliable electricity supply." The NES states: "Advanced research and development in fusion energy also could provide high-technology spinoffs in such areas as superconducting magnets; high speed computing; high-power lasers; electronic diagnostic equipment; and high-power, high-frequency radio sources. Further, fusion technology developed within the United States could help enhance the Nation's position as a major supplier of energy and energy technologies in the world market."

Fusion Power Associates endorses the statements of the FPAC and the NES with respect to the importance to the Nation and the World of developing fusion and fusion technologies for the public benefit. Furthermore, we believe that these benefits should be developed on the earliest possible time scale and with the active participation of U.S. industry. Action from the Congress is needed to accomplish these goals.

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First, there is need for authorizing legislation, followed by appropriations, to begin to undo the damage that has been caused by the budgetary decline of the last decade, in general, and the last year, in particular. It is important to begin again to build new, advanced, experimental fusion facilities to capitalize on the steady growth in knowledge and accomplishment of the past two decades. These new facilities are needed to provide the scientific and technology/engineering data base needed for practical applications early in the 21st Century.

Second, it is important that a fusion "title" be incorporated in any national energy policy legislation that might emerge from Congress. Mrs. Lloyd introduced such legislation in the last session of Congress; Senators Johnston and Wallop have recently introduced legislation in the Senate. I am sure there will be several Bills to consider. I particularly endorse the concept, a version of which is contained in the Johnston/Wallop Bill (S.341, Section 9602), for the establishment of an Energy Security Fund that would provide funds to the DOE "without further appropriation" for a list of energy projects that the Secretary provides to Congress, "unless the list is subsequently modified by law." It is imperative, if new energy technologies like fusion are to be developed, that an adequate source of funds be found. It seems unlikely that adequate funds will be forthcoming through the present appropriations process.

It is my view that fusion can be developed on a faster time schedule than that given by the FPAC and adopted in the NES; but even their schedule cannot be met unless a doubling of the fusion budget is forthcoming over the next 5-7 years. A doubling of the fusion budget over this time period will, in fact, only restore to the program the buying power it had ten years ago. An additional doubling would be required in order to accelerate the program onto a 2015 DEMO schedule.

While proceeding expeditiously with a "focused" energy-oriented fusion program, it is important that breadth and depth be maintained in the science and technology core of the fusion program. Unless this is done, badly needed innovations required for commercial success will not be forthcoming and the fusion program runs the risk of ending up with a technological "white elephant." Last year's budget cut, and its distribution, has placed the fusion program at risk in this regard.

The DOE, in its budget submission, has indicated its intent to fund an "Inertial Fusion Energy" (IFE) program within the Office of Fusion Energy. I have supported such a program in my testimony for several years. It is a needed complementary program to the very successful inertial fusion program carried out under the Defense Programs portion of the DOE budget. The small budget requested is not, however, in my opinion, adequate to support the IFE schedule advertised in the FPAC/NES reports.

In summary, I support the budget request level for FY 1992, but I caution the Congress that new construction starts and significant increases in funding over the next several years must be forthcoming if the Energy Secretary's statement is to be taken seriously that he is transforming the fusion program from a research program into a goal oriented energy development program. The full participation of industry throughout this transformation is vital to the prospects for success.

Mrs. LLOYD. Thank you, Dr. Dean.
Dr. Glass.

STATEMENT OF DR. ALEXANDER J. GLASS, ASSOCIATE DIRECTOR, LAWRENCE LIVERMORE NATIONAL LABORATORY, LIVERMORE, CA

Dr. GLASS. Thank you, Madam Chairman.

I am here both in my capacity as an Associate Director of the Lawrence Livermore Laboratory and as the home team leader for the U.S. involvement in the ITER project. It is a privilege and a pleasure to be allowed to testify in front of the committee today. I want to thank you on behalf certainly of the people working in the fusion program at Livermore for your hospitality and for your continuing interest and support in this program.

Mrs. LLOYD. We're delighted to have you here.

Dr. GLASS. I have the honor to be the last speaker on the schedule this morning, and there is a strong temptation to simply agree with the preceding speakers and call for questions. However, I will resist that temptation.

The magnetic fusion program stands at a critical juncture in its forty year history. The long-sought goal of energy break even is at hand. As we have heard both at Princeton and at the Jet Machine in Culhan, results very close to break-even have been achieved. Scientists around the world, and those of us here in the room today, are contemplating with some concern the transition from a laboratory physics program to the development of an energy technology. That transition offers us many challenges, and, as we've heard, it requires a substantial number of changes, including, as Chairman Brown mentioned, a change in the culture. But wrenching as some of these transitions may be, along with these changes come a very exciting array of opportunities.

I think we all agree that the goal of the fusion program is to develop and evaluate a new technology to produce electrical power. We know that associated with that is a long time and a high cost. But we must keep in mind that we're talking about a technology that promises to solve our energy supply problems for all time in an environmentally benign manner, and that's not an easy task but it is a monumental objective. It is a difficult and it is a demanding task, and it is taking a long time because it requires the mastery of an entirely new realm of physics and the development of a wide variety of new technologies.

I am going to skip over many of the things that the other speakers have talked about, I don't see any reason to repeat those.

Mrs. LLOYD. Your entire testimony will be made a part of the record.

Dr. GLASS. Thank you. Then I will move quickly to the subject of ITER, and particularly the issue of industry involvement, which I know is of interest and concern to all of us here today.

ITER is the first major step down the road toward a commercial fusion technology and must be viewed as such. As Jim Decker eloquently described, it is an engineering test reactor. He went through what the performance parameters of the system will be if

it is built. And the objective of ITER is to pave the way for the construction of an electricity producing demonstration power plant.

An objective of ITER, both at the international level and at the national level, is to bring industry into the picture. The way that is specifically defined is that in the ITER EDA, a point which I think has not been made so far, roughly one-fourth of the expenditure of funds is associated with the design activity, and three-fourths is associated with the development of the critical technologies that are required. So three-quarters of the work is technology development. In terms of the ITER schedule, it is technology development that paces the schedule, not design.

The technologies that are critical to the success of the machine will be developed in the form of scaleable models—for example, the large magnetic coils prototypes will be built at one-third size—so scaleable models of all critical technologies will be built and tested during the EDA. The idea is that at the end of the EDA not only will there be a set of engineering drawings to allow a construction of the machine, but there will be qualified industrial vendors in all four participating national entities ready to bid on components.

That requires industrial participation in the form of teaming, as Dave Overskei described, from the outset of the EDA in the technology development activities. In January of this year, we at Livermore sponsored, as part of our ITER role, an ITER industry briefing to discuss with representatives of industry how best to bring industry into the ITER project. I just want to take a moment to read to you very briefly from the report which came out of that conference, and that report, by the way, is incorporated in my written testimony. There was agreement in many instances that the best operating mode for industry in ITER is as members of laboratory-industry teams. Industry would work closely with the laboratories and play the role of a full and responsible partner.

> Industry must be involved in all aspects of planning, design, decision making, resource allocation, and R&D as a full partner with the laboratories. This laboratory/industry arrangement has worked very well in the past on previous fusion projects, such as the TFTR systems engineering, design, procurement and installation done by Princeton Plasma Physics Laboratory's industrial partners Ebasco and Grumman. Another successful example was the MFTF-B design and construction at Livermore.

The main impediment at the moment—and it is not an essential difficulty but it is slowing us down in the development of a plan for industry involvement—is the question of conflict of interest. All industrial involvement in the ITER project must be competed in the present climate, and we have to arrange things so that industry's participation in the planning and initiation of an activity doesn't preclude subsequently their participation in the design and construction and testing of hardware. And that's an issue that we're working through right now on the legal side.

The added virtue of ITER, of course, is that the costs of the development will be shared among the major industrial nations of the world. And, as we've heard, in the four parties the division between industry and research efforts—in national laboratories, universities, and so on—is different from partner to partner; but I want to assure you that the involvement of industry is taken as a tenet of ITER organization at the international level and has, in

fact, been in the forefront of all the international discussions to date.

I just want to close with a comment about the necessity of having a vision in this program. A program needs to have more than objectives, more than a plan; a program to be successful requires a vision. This program has been criticized in some quarters for lack of accomplishment. With the program that's proposed incorporated into the National Energy Strategy and which is reflected in this year's budget request, I think we should stop for a moment and think about what we can accomplish in MFE, where we could be by the end of this decade.

By the year 2000, if we go forward with the plans that you've heard about today, we will have demonstrated deuterium-tritium reaction in a magnetic fusion device for the first time anywhere on the face of the earth, and we will have done that here in the United States. That should be an object of national pride.

Secondly, if we follow through on this plan, we should by the end of this decade be operating the Burning Plasma Experiment, which, as you've heard, will produce significant gain, significant fusion power in reactor grade plasma. And that will be a facility, again, that will lead the world in fusion physics and it will be a facility that will be operating here in the United States.

And finally, if we go forward with this plan, we will be by the end of this decade starting to construction on the ITER, which is both a bold step down the road toward solving the world's energy supply problems and a paradigm for international collaboration in large scientific projects.

That's a very exciting future. That's a brilliant vision, in fact. And it is in our grasp if we will make the necessary investment today.

Thank you for your kind attention.

[The prepared statement of Dr. Glass follows:]

Dr. Alexander J. Glass
Lawrence Livermore National Laboratory
Livermore, California 94550

Testimony Submitted to the
Subcommittee on Energy
Committee on Science, Space, and Technology
U. S. House of Representatives

March 13, 1991

Summary

For forty years, scientists have sought a way to harness the potential of fusion energy. Today, we are on the threshold of achieving the long-sought goal of net power production. In its 1992 budget request, the Department of Energy calls for a new emphasis on developing magnetic fusion energy technology, with the strategic goal of operating a demonstration power plant by the year 2025. The proposed program calls for an aggressive exploitation of existing experimental facilities, the construction of a new facility to demonstrate significant net power production in a burning plasma, and United States participation in the International Experimental Thermonuclear Reactor project. This program is consistent with the direction recommended in the year-long review of fusion recently completed by the Fusion Policy Advisory Committee (FPAC).

1992 Budget Request

The 1992 budget submission for Fusion Energy represents a critical turning point in the forty-year history of fusion energy research in the United States. The Department of Energy is requesting a total of $337.1 million for fusion research, in FY 1992, an increase of $297.6 million over the actual Congressional budget of FY 1991. However, in real spending power, the 1992 budget request barely brings the fusion program back to the level of spending appropriated in FY 1990, and still remains far below the spending levels of earlier years. However, the FY 1992 budget request represents a new direction for the fusion program, which emphasizes the development of a practical energy technology, with the objective of completing construction of a demonstration fusion power plant by the year 2025. To reach this goal requires a firm commitment in the near term to a set of program priorities.

MFE Priorities

These priorities are clearly stated in the National Energy Strategy document developed by the Department of Energy, and are based on recommendations

resulting from a year-long review of fusion energy conducted by the Fusion Policy Advisory Committee (FPAC). The FPAC report gave high priority to three activities within the fusion program:

(1) Conduct deuterium-tritium experiments in the TFTR facility at the Princeton Plasma Physics Laboratory (PPPL),

(2) participate in the international collaboration to design the International Thermonuclear Experimental Reactor (ITER) and to develop associated technology, and

(3) construct a Burning Plasma Experiment (BPX), as the lead facility in the United States.

Furthermore, FPAC stressed the importance of supporting these activities with a robust base program in fusion science and technology. All of these components are required to meet the objectives of the program in a timely and cost-effective manner. The development of a practical fusion energy technology will require a continuing increase in program resources over the next few years. We recognize that the federal budget is currently under great pressure, and that this situation is unlikely to improve in the near future. However, fusion energy development represents the kind of long-term, high-risk, high-reward program which can only progress through federal funding. No other source of support is available for it. Furthermore, we now have the possibility of reducing the burden on the United States budget, by taking advantage of the growing opportunities for international collaboration.

International Collaboration

The magnatic fusion program has been international in character since the 1950s. The program benefits from extensive use of bilateral agreements among the major programs in the United States, Japan, the Soviet Union, and the European Community. Modern-day fusion devices are based on international contributions to fusion technology. The tokamak is a Soviet idea, as is neutral beam heating. The H-mode, the most efficient means of confining a plasma, was first observed on the Asdex tokamak in West Germany. Superconducting magnets have been implemented for fusion devices in the United States, Japan, France, and the Soviet Union.

The ITER Project

The International Thermonuclear Experimental Reactor (ITER) project originated in conversations between Presidents Reagan and Gorbachev at the Geneva summit meeting in 1985. Under the auspices of the International Atomic Energy Agency (IAEA), the collaboration was expanded to include the European Community and Japan, along with the United States and the USSR. The initial phase of the ITER collaboration, the Conceptual Design Activity (CDA), was initiated in 1987, and was completed in December 1990. The four parties are currently discussing the terms and

conditions for the next phase of the collaboration, the Engineering Design Activity (EDA). The EDA is expected to last about six years, and will culminate in the completion of engineering drawings for the construction of the ITER facility, and in the design, development, and testing of all critical technological components. Thus, at the end of the EDA, if a decision is made to proceed, construction can begin with minimum delay.

The ITER facility is a superconducting tokamak, with external current drive. It is designed to produce 1,000 megawatts of fusion power in a burning D-T plasma. It will operate initially with long pulses of several hundred seconds duration or more, and eventually, in steady-state, continuous operation. ITER will incorporate a tritium-breeding blanket, so that its operation will not be dependent on external sources of tritium. In continuous operation, it is expected that ITER will regenerate upwards of 80 percent of its tritium requirement.

ITER will operate in two phases. In the physics phase, the objective will be to explore long-pulse ignition and control of a burning plasma. Near-ignition conditions will be sustained for pulse durations of several hundred seconds. In this phase, ITER will address critical issues of burn physics, refueling, and helium removal, as well as plasma stabilization. In the testing phase, ITER will serve as a test facility for neutronics, blanket modules, tritium regeneration, and advanced plasma technologies. External current drive will be used to extend the pulse length, with the ultimate goal of continuous operation.

In February, a panel of technical experts, chaired by Professor David Baldwin of the University of Texas, reviewed the ITER conceptual design in detail. They concluded that the CDA activities provided an adequate basis to justify proceeding to the EDA. They observed that the CDA design will need further development to assure greater margin for achieving the desired operating conditions. However, they concluded that the proposed ITER schedule could be maintained, as long as the final engineering design could be frozen no later than 1993. The reviewers emphasized the importance of establishing the testing mission as the primary objective of ITER.

ITER Organization

During the CDA phase, ITER expenditures equaled about $16 million per year from each of the four parties, totaling about $200 million worldwide, over three years. Half of this total was spent on technology development, carried out in laboratories in the home countries of the participants, while half was spent on design analysis. A central design site was established in Garching, just outside Munich, in West Germany. Each of the four parties designated a Managing Director. The project was managed by the four Managing Directors, acting as a committee. The Japanese Managing Director, Ken Tomabechi, served as project director. The United States domestic effort during the CDA was led by the Lawrence Livermore National Laboratory (LLNL), which was designated as U. S. Lead Laboratory, under the direction of the Office of Fusion Energy.

The ITER organization during the EDA will differ significantly from the CDA arrangement. The four parties will appoint an ITER Council, which will serve as a "Board of Directors" for the project. A project Director will be designated by the parties, along with several Deputy Directors. The Director and Deputies will be employees of the ITER project, and will be responsible to the Council. In each of the four parties, a Home Team Organization will be established, led by a Home Team Leader. (In the United States, I have been designated as Home Team Leader.) A project office will be established at LLNL, to provide administrative support to the project. The technical organization for the United States will be made up of the best available scientists and engineers, drawn from various U. S. laboratories. It is intended that the ITER Home Team will be a national effort, rather than concentrated in one laboratory.

The Central Team will be staffed with personnel seconded from the four participants. The location of the Central Team is still undecided. The United States has proposed a site in La Jolla, California, while the Japanese propose a site at Naka, northeast of Tokyo, and the Europeans propose the site in Garching which played host to the CDA. The Soviet Union did not propose a design site for the EDA. The Central Team will be responsible for design integration, project coordination, and much of the overall engineering design. The Home Teams will undertake specific design activities, and will be responsible for the development and testing of all critical technologies. During the EDA, it is estimated that the four parties will spend over one billion dollars (in FY 1990 dollars), with three-quarters of that total spent on technology R&D and testing of scalable model components.

Industry's Role in ITER

One of the objectives of the EDA is to develop and test scalable models of all critical technologies needed in the construction of ITER. At the national and international level, the project is committed to the principle that these model components will be constructed in industry. The goal of the EDA is to prepare for the construction phase. Industrial organizations in each of the four participants must be prepared to bid on the construction of the facility. Thus, during the EDA, technologies which are currently resident in national laboratories or in universities must be transferred to industry. Industry will participate in the design and testing of ITER technology, and will take a lead role in manufacturing the final components.

To get a better understanding of how to involve industry in the ITER EDA, LLNL, in conjunction with the Electrical Power Research Institute (EPRI), held a day-long ITER Industry Briefing in January. We asked industry representatives for their views of how best to facilitate industry participation in ITER. A strong recommendation was the early formation of laboratory-industry teams. A copy of the summary of industry comments from that meeting is appended to this testimony. Technology transfer is receiving a new emphasis in the Department of Energy. The Secretary recently issued SEN-30-91, entitled "Setting the Course for Technology Transfer at the Department of Energy," which calls for increasing the level of industry participation in all DOE

research and development programs. The ITER EDA, encompassing both engineering design and technology development, provides an opportunity to increase industry's role in the development of fusion energy, albeit within a limited budget.

Tokamak Experiments in the United States

ITER is one element of the national MFE program. Its success depends critically on the availability of data and technology from the other parts of the program. In particular, experience with burning plasma operations on the proposed Burning Plasma Experiment will significantly shorten the duration of the physics phase of ITER operations, and allow the experiment to move more quickly into the testing phase, which is ITER's primary objective. The BPX will provide valuable experience in radiation-hardened diagnostics and tritium handling, which will also directly benefit ITER operations.

The Department of Energy proposes to start construction of the BPX at PPPL in 1993, with completion by 1998. If constructed on this schedule, BPX will be the first facility in the world to demonstrate near-ignition conditions in a fusion device, and high energy gain. BPX will operate with pulse durations only up to ten seconds, since it does not use superconducting magnets. However, it will provide extensive data on energy confinement, and its operation will firmly establish the scientific feasibility of magnetic fusion.

All approaches to fusion energy contemplate the use of a mixture of deuterium and tritium (D-T) as fuel. The D-T mixture is the easiest to ignite of any known fusion reaction. To date, however, no magnetic fusion experiment has been carried out with D-T fuel. All results to date have been obtained with pure deuterium, and the results extrapolated to the expected D-T performance. The fusion program plan calls for experiments within the existing TFTR facility at the PPPL with D-T by 1993. These experiments will demonstrate near-breakeven conditions, and will provide valuable experience in handling tritium.

The United States magnetic fusion program currently concentrates exclusively on the tokamak approach to confinement. At General Atomics, the D-III-D tokamak provides a wealth of physics results. It is the largest tokamak in the United States equipped with a non-circular plasma cross-section and a divertor, which are features characteristic of all modern tokamaks. At MIT, construction of the C-Mod tokamak will be completed this year. C-Mod also features a non-circular plasma cross-section and divertor, and, like the proposed BPX, is designed to operate with a very intense pulsed magnetic field..

The LLNL Magnetic Fusion Program

Several other small tokamaks operate at various laboratories in the United States. At LLNL, the MTX experiment combines a small, high-field tokamak, Aleator-C with a powerful free-electron laser, to examine the interaction of intense, ultra-short-

wavelength radio waves (millimeter waves) with a magnetically confined plasma. The frequency of these waves can be tuned to a resonance with the electron cyclotron motion in the magnetic field, a technique called electron-cyclotron heating (ECH). ECH can potentially be used to heat the confined plasma, or as an external driver for the plasma current. The MTX experiment is a collaboration between LLNL and the Japanese Atomic Energy Research Institute (JAERI). The experiment is scheduled for completion in 1992.

Livermore scientists also participate in experiments conducted at the D-III-D facility at General Atomics. A Livermore experimental team is in residence in San Diego. LLNL experiments on D-III-D emphasize the study of the physics of the plasma edge, a region of vital importance in understanding stable confinement and impurity control.

The physics of tokamak-confined plasmas is very complex, and innately three-dimensional. On a small scale, local fluctuations of plasma density, temperature, and magnetic field intensity create turbulence-like conditions, which profoundly affect the transport of energy through the plasma. The LLNL theory group is one of several in the United States developing new computational techniques to model these turbulent transport processes. Application of these techniques will allow us to run "numerical experiments," which will extend our understanding of transport phenomena beyond the realm accessible in the laboratory.

The success of fusion depends on both a comprehensive understanding of the relevant physics and the development of critical technologies. At LLNL, we have emphasized technologies vital to magnetic fusion. As previously mentioned, we have pioneered the use of free-electron lasers to produce millimeter waves for plasma heating and current drive. We are also working with Varian Associates to develop high-power gyrotrons, which are electron tube sources of millimeter-wave radiation. megawatt gyrotrons are ultimately intended for installation on D-III-D.

If magnetic fusion devices are ever going to operate continuously, they will require reliable, superconducting magnets. At LLNL, we have built the largest superconducting fusion facility in the world, the MFTF-B mirror machine, which is no longer operational. Using components from MFTF-B, we have constructed the FENIX facility for testing superconducting coils. The facility is nearing completion, and we shall be testing model coils supplied by European and Japanese laboratories later this year. We also expect to use our testing facilities in the development of superconducting magnets for ITER.

Conclusion

The 1992 budget request reflects the change in emphasis in the DOE's Magnetic Fusion Program from a research orientation to the development of an energy technology. Three activities have received high priority in the program, D-T experiments in TFTR, participation in ITER, and construction of the BPX. However, as

emphasized in the FPAC report, the successful development of fusion energy requires a broad spectrum of activities, including both physics and technology. Several facilities need to be constructed to provide the data needed to support the construction of a demonstration power plant in 2025. The FPAC report recommends construction of a source of 14-MeV neutrons for materials testing, and a steady-state tokamak for development of efficient means of current drive. It also emphasizes the need for a robust base program of physics and technology development, including the exploration of advanced concepts for improved confinement. The current United States program provides for only part of the effort envisioned by FPAC. Clearly, further increases in the U.S. fusion budget beyond the level requested for FY 1992 will be needed to fulfill the FPAC recommendations.

A significant reduction in the cost of this program to the United States can be achieved by constructing the major facilities on an international basis, with cost sharing among the participants. The ITER project provides an outstanding example of the benefits of this approach. However, it must be realized that in order for the United States to play a major role in the world fusion program, we must support our involvement in international projects with a strong program at home, and we must demonstrate our ability to honor our international commitments, even in times of great budgetary uncertainty.

AJG:mcr
03/08/91

ITER INDUSTRIAL BRIEFING

January 15, 1991

Summary of Round Table Discussions on Industrial Participation in ITER

On January 15, 1991, the Electric Power Research Institute and the Lawrence Livermore National Laboratory jointly sponsored a briefing for industry on *Opportunities for Industrial Involvement in the ITER Project.* As part of this ITER Industrial Briefing, a round table discussion was held on the topic of *Industrial Participation in the ITER Project.* This round table was composed of 8 senior industrial technical leaders, each of whom had significant previous personal technical involvement in fusion, and each of whom represented a firm with major industrial participation in the fusion program. The panel members were:

Stephen O. Dean	–	Fusion Power Associates – Chairman of Round Table
John Davis	–	McDonnell-Douglas
Robert Rocco	–	EBASCO
David Overskei	–	General Atomics
Paul Reardon	–	SSC
Robert Botwin	–	Grumman
S. Locke Bogart	–	General Dynamics
James Maniscalco	–	TRW

The panel members had been asked by Dr. Alexander Glass of LLNL to give their views on the role industry should play in the US team participation in ITER. They had been asked to consider the following questions:

1. What are the most effective ways to strengthen industry's role in the Magnetic Fusion program, in light of current budget realities?

2. How can we develop effective teaming between industry and the national laboratories?

3. How can US industry obtain maximum benefit from technology developed elsewhere in the world in the ITER project?

4. How can we most effectively prepare US industry to compete in the construction phase of ITER?

As a result of the round table panel discussions, a number of common themes emerged that are noted in this section. The round table panel participants were all individuals who have demonstrated great personal commitment to the fusion program in the past. All expressed extreme pleasure that the fusion program has survived the very difficult budget times of the 1980's, has made tremendous technical progress, and is poised to move forward towards an experimental fusion reactor. The panel highlighted the need to emphasize that fusion is an energy program, not just a physics research program in order to attract long-term

industry and utility interest. It was pointed out that fusion is an ideal example of a highly appropriate governmental function. In the world fusion programs, the governments of the respective parties are carrying out research and development that is inherently long-range, high risk, and of uncertain commercial payoff. However, the potential benefits of this research to the countries supporting it is very large. This is the very sort of activity that governments must carry out for their citizens. Because of the magnitude of the effort, and the magnitude of the potential payoff, it is entirely appropriate that fusion become a program of significant international cooperation and interdependence. The ITER program is the first major step in this direction.

There was clear consensus among the panel members that US industry is currently significantly under-represented in the ITER program, as well as the US fusion program in general. The European community and Japan have significantly more industrial involvement in their fusion and ITER programs. It was suggested that at this stage in fusion development, which might be termed the "plasma engineering phase," the appropriate industrial participation might be ~40%. US industry has had only a small role in ITER so far. US industry should have helped participate in the development of the design and of the R&D plans for ITER. At the very least, industry should be rapidly involved in the early stages of the EDA to review the design and the associated R&D plan before the first steps of implementing this design and this plan are taken.

US industry can not take fusion or ITER seriously until the DOE changes its present policy towards fusion and towards industrial involvement in fusion. At present, it appears DOE regards fusion as a research program, not an energy development program. Further, there is no commitment to industrial involvement. DOE must implement a policy for the development of a US fusion industry, and that policy and the associated industrial support must be maintained despite fusion program changes due to budgetary uncertainties.

Concern was expressed that the US fusion program has made too many false starts during the past decade. DOE must somehow make a commitment that ITER, or something very similar to ITER, will actually move forward from design studies to actual construction if industry is to become seriously interested in participation. Given the long-term and uncertain nature of the fusion development program, it is unrealistic to expect industry to participate in ITER without DOE financial support. DOE appears to want US laboratories, universities, and industry to do a superb job representing the US on the ITER project, but is presently unwilling to provide either the funding or the firm program direction needed to insure that this superb effort can be provided.

There was agreement in many instances that the best operating mode for industry in ITER is as members of laboratory/industry teams. Industry would work very closely with the laboratories, and play the role of a full and responsible partner. This will provide the maximum synergism of the characteristics of national laboratories and industry, will optimize technology transfer to those industries, and prepare industry to commercialize fusion in the future. Industry must be involved in all aspects of the planning, design, decision making, resource

allocation, and R&D as a full partner with the laboratories. This laboratory/industry team arrangement has worked very well in the past on previous fusion projects, such as the TFTR systems engineering, design, procurement and installation done by PPPL's industrial partners Ebasco and Grumman. Another successful example was the MFTF-B design and construction at LLNL. TRW and General Dynamics worked very closely with LLNL to carry out this project. The round table participants were apparently surprised and for the most part in disagreement with the idea suggested by DOE that a single industrial partner be selected for the entire US-ITER project effort. Preference was indicated for the formation of a number of separate laboratory/industry teams for each of the major systems or components.

The presentations from the ITER team had emphasized the role that industry might play in ITER R&D. There was strong feeling expressed by the panel that industry must be involved not only in R&D, but in the design and R&D planning as well. Industry is particularly suited for design responsibility, and without this responsibility in the Title 1 design, would be ill-prepared to participate in the construction phase.

There appeared to be significant uncertainty regarding the goals and the operating mode of the ITER program. ITER is in actuality a process rather than a project. The US will contribute one-quarter to this process, and must interface its efforts with those of our partners. Much of the design effort is planned to be done by a central team that will have full design authority without technical direction from the home teams or home management. US industry is much more accustomed to project-oriented operation where lines of corporate responsibility are clearly drawn. Parallel competing design efforts, with down-selection following completion and competition, are the normal mode of operation. The goals, responsibilities, and structure of the ITER project must be clearly and forcefully defined for the program to be effective. Several panel members expressed concern that a commitment to construct ITER was necessary at this time. Other panel members, however, were confident that the ITER process would be of significant value to the US/Fusion program, even if a construction commitment could not be made presently. The project direction, however, must be clearly defined in terms of an intent to construct. ITER with an intent to construct, even without a formal commitment to do so, would be a much different program from an ITER whose main goal was enhancing the knowledge base of the global fusion program and would require significantly different US industrial and laboratory goals.

Some concern was expressed from round table participants that the cost and schedule estimates for the ITER engineering activity are unrealistic. It was pointed out that the engineering design of a light water reactor costs from $500M to $800M. This effort is done by a close-knit team with a great deal of experience with similar previous designs. It may be unrealistic to expect that the first-of-a-kind ITER can be designed by an international team for only $200M. Licensing time for light water reactors presently take 8 to 10 years in the United States. It is unrealistic to expect that ITER will take less time if it were to be built in the US. Although the safety risks of fusion are expected to be significantly lower than fission, the fact that it will be the first-of-the-kind license submittal will cause additional delay.

SUMMARY

Alex Glass closed the meeting with a summary of the key points he believed he had learned from the ITER Industrial Participation round table. Industrial representatives indicated that US industry needed the following things in order for them to participate meaningfully in the ITER program:

1. A commitment for a serious fusion development program, and for industrial involvement in that program.

2. An emphasis on an energy mission for fusion rather than physics research.

3. Opportunities for broad participation in ITER and broad access to the knowledge base ITER will develop.

4. Provision of adequate budget to do the job right.

5. A commitment, or at least a firm intent, to actually build the ITER machine.

Mrs. LLOYD. Thank you very much for your excellent testimony. I would say that I've never had better testimony than we've had today. I want to congratulate all of you for a job well done.

On the ITER program, Dr. Glass, it is our impression that the Europeans have a different view on the need of a blanket breeder to breed tritium. I would like for you to clarify this relative to our view, if you would.

Dr. GLASS. Yes. The different view derives from a different emphasis on the mission of the machine. ITER is planned to operate in a physics phase, in which it will be a long-pulse burning plasma experiment, and then in a technology phase, in which it will provide a test bed for the development of nuclear components and of other components for the demonstration reactor.

In the United States, we feel strongly that the emphasis should be on the second phase, on the engineering features of the device. In order to do the nuclear testing, it is felt that a cumulative fluence in the order of 1-to-3 megawatt years per meter squared, neutron fluence, must be achieved in the machine during its operating lifetime. That will allow us to test nuclear components to the extent that is really required. In order to do that, you can calculate easily how much tritium you have to burn under those circumstances, and you can calculate the cost of that tritium. And you come to the conclusion that that cost could be the dominant cost for the machine unless the machine is capable of regenerating a large fraction of the tritium that it consumes. And it is that logic that leads the U.S. to the point of view that we should have a tritium breeding blanket in the machine so that it can regenerate somewhere in the order of 80 percent or more of the tritium that it burns.

Now the European point of view, at least as expressed by some members of the European Community, has been that the emphasis should be on the first phase, the physics phase. During the physics phase, the amount of tritium that is consumed is significantly less—the availability is lower, the operating time is less—and, therefore, there is a less compelling reason to go to what they perceive as the added complexity of a breeding blanket. So the difference in viewpoint with regard to the breeding blanket really reflects a difference in emphasis as to what the mission of the machine should be.

Mrs. LLOYD. Okay. You said that technology development would determine the pace of the program. It seems to me that you have a good many legal impediments as would clarify what each role would be, especially when you have international collaboration with industry. Do you think you've got some major obstacles to hurdle?

Dr. GLASS. Well, I was very apprehensive when I first became involved in the discussions with regard to the question of proprietary rights, rights in data, and the issue of ownership of technology, and access to technology. However, this issue seems to have been worked out, at least on paper, to the satisfaction of all four parties in the process of formulating the EDA agreements. That is, we have a draft agreement which treats the issue of the maintenance of the protection of proprietary property while allowing access to

technology developments that are acquired during the ITER process.

There are a lot of issues that will not really be tested until we get into the actual operation of the ITER EDA. The first time that someone from the United States calls up a Japanese industrial laboratory and says, "I want to come by and look at what you're doing for ITER," or similarly the first time somebody from another country calls up certain U.S. laboratories and says, "we want to come by and see what you're doing for ITER," that will be the time that the validity of these agreements really is put to the test. We are not unaware of these issues and these have been worked on at least at a very high level in the Government, in both the Department of Energy and in the other departments that have been involved in the interagency coordination for the ITER project.

Mrs. LLOYD. Something I've thought about a long time, when do we have—of course you know that I am very much a proponent of industrial participation and international cooperation—but at what point when we do bring industry in as teams do we have too much international collaboration? Dr. Forsen, would you like to comment on that?

Dr. FORSEN. Yes. I think that is a ways off.

Mrs. LLOYD. I'm still wondering about it, Dr. Forsen.

Dr. FORSEN. You heard Dr. Parker say in answer to a question from Congressman Schiff, 50 years. I would like to comment on that while getting to your question, if I might.

I think part of the problem here is what is the national need and what can the national budget afford in bringing fusion forward. And I don't think 50 years is the target date given either one. If we needed it sooner or could afford to do it sooner, I think we could. The point then that comes about in industrial participation and international competitiveness is that U.S. industries really are not able at this time to understand the full broad elements of the fusion system.

The national laboratories rightfully contend that they spend 80 percent of any budget with U.S. industries in getting the projects done. But U.S. industries have not yet had the responsibility nor the ability to carry out fundamental designs in fusion such that they are prepared to carry any risk. We have not brought those industries in that have experience in nuclear, and these are nuclear power plants albeit much kinder. The utilities who would buy those plants would be looking at those industries they are used to dealing with, and, clearly, the Nuclear Regulatory Commission is going to have to play its role in it.

So I am worried more about how we get the system side, the large aspects of fusion power done, and we can't do that before we get the details done. I think ITER will allow us to spend a lot of time and get a lot of talent involved from industry in the details. But a competitive team that gets one winner or two winners does not develop a U.S. industry to provide the full system. Consequently, there has to be more thinking in this, in my view.

I don't think we're going to run—to answer your question finally—into competitive sides of this until we start building the ITER. And that's a separate question from the design, which I think we can all look at, we can all look at the prototype development and

testing, and I think the Japanese industries will let us go look at what they are doing. But when we start building the real one and some innovation and some special techniques become involved in how that flows in to this reactor, then we're going to have more difficulty.

Mrs. LLOYD. Are you concerned about what could be the result if industry doesn't participate the way that you envision?

Dr. FORSEN. The result of that is, as I am convinced, the Japanese industries will participate the way they envision—and are doing it now; they are already involved with building all of the machines in Japan. They do not have the ability, in the equivalent of their national laboratories, like we do to carry out full design and construction management of those activities. The Japanese build everything, so they have got the skills in-house to build all of the components that we want to learn how to do. The Germans are someplace—the Europeans, I should say—are someplace between we and the Japanese. We need to get up to that level of sophistication.

Mrs. LLOYD. You mentioned we needed a more formal effort, that this needs to be an issue. I would like for you to elaborate a little bit more on your philosophy.

Dr. FORSEN. Part of the problem that the Department has had is sustainable budgets, you've heard about them particularly from Dr. Dean. The laboratories and the universities are where the real talent in the fusion program is today. To sustain that effort when the budget goes through its cycles, those are maintained and the industries come in to carry out small roles as can be afforded and as fit.

We need to maintain a program that allows continuity. The private sector is not prepared to make any investment in fusion because it has no payoff for its shareholders in the foreseeable future. Nonetheless, we need the talent that they have and to build the experienced database among its young and experienced people in those industries to be the nucleus for carrying out the longer-term program. I think the formalization of the certain fraction of the budget will be prepared and used by industry. Whether it is competitive bidding or a formalized program in technology transfer, it needs to be a part of what we're doing.

The reason many of us are excited about ITER is because the detailed design that's required of ITER—and even if the U.S. only does its quarter share of it, it needs to understand the full system, and it will do that I'm sure—the detailed design is not something that the national laboratories and universities bring a lot to the party. That's the kind of thing that U.S. industry does. And so here is a real opportunity for them to get involved and understand the pieces of this system and the overall system elements of it so that they are better prepared longer-term to be competitive in any part of it.

Mrs. LLOYD. Good luck.

Dr. Dean, what heroic efforts should be made do you feel to begin construction of BPX in 1992?

Dr. DEAN. I'm sorry, what was the first part of your question?

Mrs. LLOYD. What heroic efforts. [Laughter.]

Dr. DEAN. Well, we have had some discussion in the community about how to approach this particular budget year. In the past we would have probably come forward to you and asked you to add money to the budget and accelerate the approval process for the BPX. I guess it is kind of our consensus that there is really not much hope for that in this particular budget climate, so we're not asking——

Mrs. LLOYD. Well, let's go back to what Dr. Glass said, that technology development determined the pace. My point is the project ready for that step?

Dr. DEAN. Well, as I mentioned, the project that has now got the name BPX has been ready to move forward for a number of years. The fact that it hasn't moved forward has allowed, as Dr. Parker indicated, for the design to evolve. And, of course, every year we get a little smarter, the design gets a little better. So you can always wait a few more years and you'll probably have a little better insight as to what to build. But it has been ready, it is ready now, and it will be ready next year. And I don't think the initiation of the BPX is in any way held hostage at the moment to some new technology development that needs to be done.

Mrs. LLOYD. You know, you do have, rightly so, several criticisms of the program this year. But basically, given the budget climate and knowing the numbers, Dr. Dean, would you shift some of those funds around if you have to have a flat budget, as we have to work with?

Dr. DEAN. Well, I think, unfortunately, within our community, and maybe this is just natural, that every one of us would distribute the budget slightly differently than every other one of us. I have my opinion and a number of other people have other opinions. I guess when it is all said and done, I think we have to let the people that are officially responsible in the Department for managing the program make the final decisions, and they have made their decisions.

I was not happy with the fact that they made these decisions last fall without consulting any of us. I had been critical of the Department two years ago when Dr. Hunter did it; I'm critical of my friends right now for having done it. But they did the best they could and I think we have to live with it.

Mrs. LLOYD. Thank you very much.

Any additional comments?

Dr. FORSEN. Just a comment on the last point. We were asked, those of us who were on FPAC—although FPAC was dead at the time the final cuts were made and the decisions were there—were brought in and asked to comment on what they thought we should do. We wrote letters as to whether we believed it or didn't believe it. And I think I do support what Dr. Dean has said, they do have to run the program, but input was selected from a finite number of people.

Mrs. LLOYD. Well thank you very much. I would like to recognize Dr. John Shefield who is here from Oak Ridge National Laboratory. He is certainly one of the good friends and great scientists in the fusion program. Thank you for being here with us.

I would like to thank all of your for your participation today. It has been a good hearing and for that I do thank you. By the way, I

forgot to ask for unanimous consent for the entry of all opening statements in the record, and I will give unanimous consent.

Thank you very much.

[Whereupon, at 11:03 a.m., the subcommittee adjourned, to reconvene at the call of the Chair.]

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APPENDIX I

SUBCOMMITTEE ON ENERGY

FUSION ENERGY FISCAL YEAR 1992 BUDGET REQUEST

SID MORRISON

OPENING STATEMENT

MARCH 13, 1991

THANK YOU MADAM CHAIRMAN. I JOIN YOU IN WELCOMING OUR GUESTS WHO ARE HERE TO TESTIFY ON THE ADMINISTRATION'S FUSION ENERGY BUDGET REQUEST FOR FY 1992.

FUSION ENERGY HAS ONE OF THE MOST INTERESTING POTENTIALS IN THE LONG TERM OF ANY ENERGY SOURCE NOW UNDER RESEARCH. IF FULLY DEVELOPED FUSION ENERGY IS EXTREMELY EFFICIENT, ENVIRONMENTALLY ATTRACTIVE AND ITS FUEL IS NEARLY INEXHAUSTIBLE, SINCE IT CAN BE EXTRACTED FROM WATER.

THE PROGRESS OF FUSION RESEARCH IS SLOW BY THE STANDARDS OF OUR HURRY-UP SOCIETY, BUT IN THE LAST 40 YEARS TREMENDOUS STRIDES HAVE BEEN MADE THAT CANNOT BE OVERLOOKED.

THE COMMITMENT OF DOE IN THIS YEAR'S BUDGET REQUEST REPRESENTS A NEW DIRECTION FOR THE FUSION PROGRAM. THAT DIRECTION IS TO MOVE TOWARD A DEMONSTRATION FUSION PLANT BY THE YEAR 2025 AND OPERATION OF A COMMERCIAL POWER PLANT BY THE YEAR 2040.

I LOOK FORWARD TO THE TESTIMONY AND THE CHANCE TO FOLLOW UP WITH A FEW QUESTIONS.

THANK YOU.

JERRY F. COSTELLO
21ST DISTRICT, ILLINOIS
113 CANNON BUILDING
WASHINGTON, DC 20515-1321
TEL. (202) 225-5661
FAX (202) 225-0285
1316 NIEDRINGHAUS AVENUE
GRANITE CITY, IL 62040
TEL. (618) 451-2122
FAX (618) 451-2128
8787 STATE ST., SUITE 207
EAST ST. LOUIS, IL 62203
TEL. (618) 397-8833

Congress of the United States
House of Representatives
Washington, DC 20515-1321

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U.S. REP. JERRY F. COSTELLO, ILLINOIS

COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY

SUBCOMMITTEE ON ENERGY

AUTHORIZATION OF THE DEPARTMENT OF ENERGY'S FY 1992 BUDGET REQUEST FOR FUSION ENERGY PROGRAMS

MARCH 13, 1991

Madam Chairman, today we gather to listen to our distinguished witnesses talk about the upcoming FY 1992 budget request for fusion energy program.

As we begin to develop a national energy policy, it is important to look at every possible alternative. I look forward to working with you, Madam Chairman, in keeping fusion energy one of these alternatives.

I look forward to hearing from Dr. Decker and other witnesses as we lock at funding levels, new construction and the industries role in fusion energy.

Madam Chairman, I thank you for calling this hearing and I anticipate some interesting and relevant commentary by our witnesses.

THIS STATIONERY PRINTED ON PAPER MADE OF RECYCLED FIBERS

APPENDIX II

Statement of

John Sheffield

Director

Fusion Energy Division

Oak Ridge National Laboratory

Managed by Martin Marietta Energy Systems, Inc.

for the Department of Energy

under contract DE-AC05-84OR21400

For the

Subcommittee on Energy

of the

House Science, Space, and Technology Committee

March 13, 1991

Statement of

John Sheffield

Director
Fusion Energy Division
Oak Ridge National Laboratory

to the

Subcommittee on Energy
of the
House Science, Space, and Technology Committee

March 13, 1991

Madam Chairman, thank you for giving me the opportunity to provide written testimony on the Magnetic Fusion Program to the Subcommittee on Energy. I find it very encouraging that the Department of Energy, through the leadership of Admiral Watkins, is proposing to move the fusion program forward into the energy technology phase. The program has made steady progress in recent years, and we should not delay in capitalizing on the advances. The recent report of the Fusion Policy Advisory Committee confirms the importance and vigor of the program and recommends moving ahead with important new initiatives, the Burning Plasma Experiment (BPX) and the International Thermonuclear Experimental Reactor (ITER). The BPX and ITER are important to the future of fusion both in their own right and because they represent, respectively, an unprecedented level of national and international collaboration. The report also recognizes the need to underpin and complement these initiatives to ensure both their success and their relevance to an energy program. The Oak Ridge National Laboratory (ORNL) is pleased to be a part of these exciting collaborative ventures.

I feel, strongly, that it was very unfortunate that the budget reduction in FY 1991 required the Department of Energy (DOE) to take immediate measures to cut the supporting programs. In the words of the Secretary, this resulted in "prematurely narrowing the program to conventional tokamaks only," through the near elimination of the Concept Improvement element of the magnetic fusion program. One outcome of the decision was the mothballing of the Advanced Toroidal Facility (ATF) at ORNL.

The ATF device is uniquely suited to contribute significantly to the current U.S. tokamak-based strategy as a valued complementary part of both the U.S. and world programs. ATF is a toroidal device, closely related to the tokamak. It has a performance comparable to a tokamak of similar size. Because it has no need for a current to be driven in the plasma, it is intrinsically steady state and free from plasma disruptions. It has also demonstrated access to a higher region of plasma pressure, the so-called second-stability region. These are features which would materially improve the tokamak if they could be incorporated in some way. They are in fact the reason that ATF was built as a part of the tokamak program. Thus, because of its design flexibility, the ATF can be used to investigate toroidal physics issues directly relevant to the tokamak; and, by implementing its ultra long-pulse/steady-state capability, ATF could be a valuable technology test bed. While we recognize that the size and timing of the FY 1991 funding cut was such that the DOE had to take drastic action, we look forward to a technical review of the ATF in the context of the new program with a view to renewing support for ATF in FY 1993. In the meantime, the ORNL experimental effort is being redirected to support of tokamak programs in the U.S., notably at General Atomics and the Princeton Plasma Physics Laboratory, and abroad.

Madam Chairman, we continue to appreciate the support of you and your Committee for fusion and hope that you will be able to facilitate the efforts of DOE to advance the realization of fusion's potential as an energy source.

Written Testimony for the
Subcommittee on Energy of the
Committee on Science, Space, and Technology

by

Rulon K. Linford
Program Director of Magnetic Fusion Energy
Los Alamos National Laboratory

March 13, 1991

I appreciate the invitation to submit this written testimony extended to me in Madam Chairman Lloyd's letter of March 7, 1991. The events of the past several months have been most unfortunate for the Magnetic Fusion Energy program nationally and at Los Alamos. While we should put the past behind us and focus on the future, I believe that a few comments about the recent events are germane in setting goals and expectations for the future.

Impact of Recent Events on Long-Range Plans

The budget cut by Congress was responded to by a change of policy by the Department of Energy (DOE) to eliminate alternate concepts in the MFE program. As a result, all of the MFE experimental plasma research activities that were being carried out at Los Alamos were terminated. All but a few of the people are gone and the facilities are being dismantled. The impact on the Laboratory is substantial and it is difficult to describe the effect on the people, many of whom have dedicated their lives to making the dream of fusion power a reality.

As severe as these impacts are, I predict that the most severe impact will be on the long-term success of the US fusion program unless corrective action is taken. By corrective action, I do not mean the restoration of the terminated alternate concept programs at Los Alamos or other institutions around the country. In broad terms, corrective action should focus on reducing the mismatch between the "public" expectation and the most likely results to come from the program that is now being carried out.

The Fusion Policy Advisory Committee (FPAC) recommended the goal of an operating demonstration plant by 2025 and pointed out that meeting this goal would require at least doubling the fusion budget. The present budget request for FY 1992 falls far short of the FPAC recommendation, and yet the goal of a demo by 2025 does not appear to have changed. The disparity between the goal and the budget will intensify the mismatch between public expectations and what the funded program can deliver. Public leaders, including members of Congress, remember the projections made 15 years ago that a demo could be built around the turn of the century. Unfortunately, the projected budget requirements of over 1 billion dollars per year (in today's dollars) tend to be forgotten. Those budgets were never achieved, and even though we can be proud of the progress made with the available funds, the MFE program's reputation still suffers severely from the mismatch between that progress and the public expectation of faster progress. The disparity now between the present budget level and the 2025 goal does not make it look like we have learned from the past.

I would very much like to see the FPAC recommendations implemented, but if the recommended budgets cannot be achieved, then the goal for the demo should be delayed correspondingly.

A second and more subtle cause for a potential mismatch between expectations and realistic projections is the content of the program. The impact of eliminating alternate concepts and down playing the importance of concept improvement has been characterized as increasing the risk or eliminating an insurance policy. This characterization is supported by the logic of the remaining program, which shows smooth transitions from studying burning plasmas to developing nuclear technologies in ITER to constructing the demo. I believe the ITER-demo transition will not occur without concept improvement. As I have testified before, major improvements in the confinement of plasmas are essential for the successful development of fusion as a commercially viable source of energy. Such improvements are not just a matter of risk reduction or insurance.

The present DOE plan should yield many major advances in burning plasmas and technology. These advances are also essential for the success of fusion. However, the long-term impact of fusion strategy must be kept in mind. It will take about 15 years to design, build, and begin full operation of ITER. It would be unfortunate if, at that time, the future commercial potential of fusion were judged solely on the ITER design, which is based on today's level of knowledge. Unfortunately, present budgets are not adequate to accomplish the concept improvement work needed before a demo is built.

In terms of public expectations, it is especially important to acknowledge the need for concept improvement. This needed element in the program was explicitly acknowledged in the recent FPAC report, but it is not clearly identified in the chapter on Fusion Energy in the National Energy Strategy. Ultimately, fusion will be compared with other energy technologies, and progress in concept improvement is essential for fusion to become a desirable energy option. Therefore, concept improvement should be elevated to a recognized and vigorous component of the program plan as soon as possible. Alternates were a vital part of the previous concept improvement activity because they held the greatest promise for qualitative improvement in the confinement approach as well as providing important vehicles for advancing the underlying science of confinement. It will take years to regain what was lost in the past few months. I am not implying that all of the experiments that were terminated will have to be rebuilt precisely as they were in order to make progress; hopefully, some progress will be made in the meantime in other countries. I am stating, however, that the teams of people who have been lost were the world leaders in their areas, and were the most important resource in the concept improvement area. It will require many years to build new teams, as well as new facilities. Because of the importance to the development of fusion power, we need to embark on the rebuilding as soon as possible.

Los Alamos Contributions to the Fusion Program

As I previously stated, the present DOE program should yield many advances that are essential for fusion's development. Los Alamos is committed to contributing to this program by applying its expertise in a wide variety of areas.

An agreement has been signed recently with the Japanese to extend our very successful collaboration on the Tritium System Test Assembly (TSTA). A new fuel cleanup system built by the Japanese was successfully tested on TSTA during the past year. The technologies being developed are important for tritium operation in TFTR and any future experiment using tritium.

TFTR and other systems such as ITER that will use tritium in the future. Also, our medium-energy physics facility, LAMPF, provides a future resource for the radiation testing of materials and diagnostics. The Los Alamos expertise in accelerators will be important in developing, with the rest of the world fusion community, a more powerful facility for materials radiation testing.

Most of our theory and computational effort will continue, and the portion that was devoted to alternates will be redirected toward the tokamak concept. A number of the tools developed to handle special problems in the alternates provide a unique resource for attacking problems important to the tokamak. Our system studies will continue to contribute to the ARIES tokamak reactor study and to the divertor and edge physics studies for ITER.

During the process of closing out our experiments, we have worked to find a few ways to contribute to the experimental programs that will continue at other laboratories. With encouragement from both the Office of Fusion Energy (OFE) and the leaders at the other labs, we are developing specific plans. Thanks to the constructive interactions with OFE through the closeout process, we have been able to preserve a few members of the experimental team to carry out the plans we are developing. These plans include the developing and fielding of diagnostics on other experiments. One of the areas of specialty will be the measurements of energetic neutrons and alphas produced by fusion reactions. These diagnostics will be important for TFTR and any other experiment that will have a significant fusion yield.

Inertial Fusion Energy (IFE) is a new area of responsibility for OFE. Los Alamos has a long history of expertise in areas important to IFE, including the physics of targets, dense plasmas, intense beams, accelerators, and system studies. We seek to contribute to the existing Heavy Ion Fusion driver program at LBNL and to help strengthen the overall IFE program.

In summary, Los Alamos continues to make important contributions to the national and international fusion program. We remain committed to making fusion power a reality.

GENERAL ATOMICS

TECHNOLOGY DERIVED FROM THE FUSION RESEARCH PROGRAM

As is true of any big science, the fusion program requires the development of advanced technologies to meet its objectives. These advanced technologies developed in fusion program facilities have important applications in many other fields.

The fusion research program thus serves as a training ground for scientists and engineers in fields as varied as superconducting magnets and high power microwaves. An active fusion research program benefits U.S. competitiveness and sustains a strong technological base.

Fusion technology spin-offs that have significantly benefitted the nation include directed energy weapon systems, superconducting magnets for medical and industrial applications, space science, supercomputing, materials development, semiconductor manufacture and communications.

PLASMA PROCESSING

Much of the work done on characterizing plasma surface effects and ion implementation in the surface of metals has come from the fusion program in studying the plasma/vessel wall interaction. The plasma processing industry finds much of the information it needs in the fusion literature. This area is intensely competitive with the Japanese, and fusion-supported plasma technology has been important in enabling the U.S. to maintain a competitive position.

- Plasma Etching is a major process in the semi-conductor industry for producing high density microcircuits and integrated circuits.
- Plasma Coating allows selected thin films to be grown on a surface by immersing the target material in a dense plasma. Plasma processing techniques are used to produce synthetic diamond films.
- TRW has developed a specific coating process to lay down films of dielectrics on metal substrates. In the TRW process, the plasmas are produced by RF (radio frequency) induction sources developed by the fusion program.
- The MIT Plasma Fusion Center spawned a spin-off company called ASTEX which is a leading manufacturer of equipment used in materials processing for the solid state industry.
- Plasmas are used to harden the surface of metal parts.

MAGNET TECHNOLOGY

Conventional and superconducting magnets of unprecedented size and power have been developed to confine the dense high-temperature plasmas.

3550 GENERAL ATOMICS COURT, SAN DIEGO, CA 92121-1194 P.O. BOX 85608, SAN DIEGO, CA 92138-5608 (619) 455-3000

- The fusion funded magnet technology has been used by General Electric, General Atomics, and Intermagnetics General in the making of high-field magnets needed in Magnetic Resonant Imaging (MRI) instruments used for medical imaging and for industrial quality control. The U.S. is the world leader in supplying MRI systems.

- Magneform is a process that allows metals to be welded without heat and to be shaped without being touched. The magneforming industry has its roots in early magnetic fusion research at General Atomics. The technology is now owned by Maxwell Laboratories.

- Using fusion-developed technology, General Atomics makes the large superconducting magnets for the magnetic separators used in the industrial purification of Kaolin clay.

  MIT's fusion work lead to cable-in-conduit approach to Nb_3Sn magnet design. This approach is now used throughout the world.

- General Dynamics' (GD) first experience with superconducting magnetics was the Fusion Large Coil Project at ORNL. Their second major magnet contract was the Mirror Fusion Test Facility magnets after LLNL. This is the basis for GD's capability to design and build magnet for the high-energy physics program including the prototype for the Superconducting Super Collider.

- Both GA and GD are applying the fusion derived superconducting magnet expertise to the Superconducting Magnetic Energy Storage system for utilities and various DoD programs.

HIGH POWER MICROWAVES

- High power microwave systems are used to heat magnetically-confined plasmas. U.S. fusion-funded programs have lead to the development of high-power gyrotrons improving on designs originated in the Soviet fusion program. Gyrotrons are a class of high-power microwave tubes a million times more powerful than previous ones of the same frequencies. Fusion funded development occurs at MIT and Varian Corporation.

- Microwave tubes similar to those used for plasma heating are now being developed by General Atomics, Varian, TRW, and Hughes, EIMAC. These oscillators and amplifiers offer advantages such as high efficiency, high power, and high frequency and are very attractive for defense applications such as radar, and electronic warfare as well as defense and commercial communications.

- High power microwave sources are being investigated to provide uniform heating and sintering of large ceramic items which would lead to another very large market.

- A large fraction of the Ph.D's hired by the U.S. microwave tube industry over the last ten years have received their training not as microwave engineers, but as plasma physicists.

PULSED POWER

The Strategic Defense Initiative (SDI) was possible owing to the many scientific and technological concepts which had been developed by the fusion program over the years.

- One of fusion's strongest contributions has been the development of pulsed-power technology including capacitors, switches, cables, etc., to meet the very high power requirements for fusion devices.

- High voltage pulsed power technology developed by the fusion program has been adopted by many companies. Aerovox Inc., Amphenol Corp., Balden Corp., Chester Cable Div., Cornell Dubilier Electronic, Maxwell Laboratories, General Atomics, TRW supplying pulsed power components and systems for defense and commercial research.

- Electromagnetic railgun launcher—many applications to defense programs.

- High power conversion system technology, developed for fusion, has been adapted and applied to the DC-AC conversion systems for mass transit propulsion. Applications include linear induction motor drives and auxiliary inverters.

ACCELERATOR TECHNOLOGY

Much of the technology base supporting the development of neutral particle beams, electron beams, microwave beams and free electron lasers for weapon systems had its origin in magnetic fusion energy research.

- The Advanced Test Accelerator (ATA) at Lawrence Livermore National.Laboratory (LLNL) is the state-of-the-art in high current linear induction electron accelerators. The concept of a linear induction accelerator was developed for use on the Astron project as part of the magnetic fusion program.

- Neutral Particle Beams were developed to heat plasmas to fusion.temperatures of millions of degrees. This technology has been transferred to SDI, since the high beam powers attained in the fusion program are attractive as potential weapon systems and to the plasma processing field. RCA, TRW, General Atomics, Grumman, and McDonnell Douglas all now have expertise in this area.

- The Free Electron Laser (FEL) has created substantial interest as a directed energy weapon and also has medical applications.The FEL is based on the interaction of a relativistic electron beam with a periodic magnet field, an outgrowth of plasma physics research. This technology now has been transferred to Boeing, TRW, and General Atomics among others.

- Fusion plasma experiments have been very useful for studying the highly excited species required for X-ray Lasers. The major research on X-ray lasers at LLNL has a direct connection with the Inertial Fusion Program. The recent X-ray laser experiments conducted at Princeton are based on previous work

done on fusion plasmas and diagnostic development. The PPPL X–ray laser program was winner of 1R–100 best scientific developments for 1987–1988.

- Inertial Confinement Fusion is being explored as a means of testing nuclear weapons designs and as a possible fusion energy source. From its inception in the late 1960s, this field has become a vital contributor to the understanding of the physics of high density plasmas. Many scientists active in ICF research were trained as part of the Magnetic Fusion Energy Program.

- Compact sources for X-ray power can be used for lithography for producing microcircuits and high resolution microscopy of live biological cells.

BASIC PHYSICS

- In the past 10 years, major advances have been made in understanding nonlinear phenomena in plasmas, and this work has been extended to other branches of physics, including high energy physics, solid-state physics, optical communications, spectroscopy.

- Fusion research has advanced the development of atomic physics which, in turn, has contributed to astrophysics, neutral and ion beam development, and X-ray laser development.

SPACE PHYSICS AND ASTROPHYSICS

Before the advent of controlled fusion research, plasma physics was motivated primarily by space and astrophysics. The fusion program benefited significantly from this early work.

On the other hand, the level of understanding of plasma in space and astrophysics has advanced greatly due to the rapid development in plasma physics driven by the fusion program.

Areas of study benefitting from this interaction are:

- Planetary and astrophysical magnetospheres involve the study of the plasma mantle surrounding astrophysical bodies.

- The solar wind transports plasma, energy, angular momentum, and magnetic field past all the planets of the solar system and interacts with each planet's magnetosphere

- Particle acceleration produced by collisionless shock waves play an important role in astrophysical plasmas and in the solar system. Much of what has been learned about collisionless shock physics came from the early fusion program.

- Stored magnetic energy is released through the rejoining of magnetic fields. This process has been very well studied both experimentally and theoretically in the fusion program. This process is related to the earth's magnetotail, strong solar flares, and may be the process that causes quasars to explode.

- The many astrophysical objects that apparently regenerate their magnetic fields are known as astrophysical dynamos. A similar magnetic field regeneration or dynamo effect is observed in reversed field pinch (RFP) configuration fusion devices.

- Spectroscopy
  Observations of ultraviolet and X-ray emissions from tokamak plasmas, particularly for iron impurity emissions, have been found to be directly comparable to solar flare spectra from the Solar Maximum Mission and other space flight observations. Direct calibration of solar flare density and temperature has been accomplished through the comparison with spectra from tokamak plasmas where density and temperature are measured independently. This data has been used for the interpretation of vacuum ultraviolet and soft X-ray astrophysical spectra obtained from various satellites such as IUE (International Ultraviolet Explorer) and will also be vital for the interpretation of spectra to be obtained with the space telescope. As a result of this work, greatly improved understanding of solar flares and coronal processes, the composition and processes in the atmospheres of other stars, and of the physics of nebular plasmas has been achieved.

  In addition, observations of light emission from tokamak plasmas have been used to identify and refine spectral line wavelengths from the soft X-ray to visible wavelengths. The line identification and intensities have provided tests for atomic theory.

DIAGNOSTIC INSTRUMENTATION

As with most aspects of fusion research, the requirements on diagnostic instrumentation are extremely demanding. The plasma environment is extremely severe, having temperatures on the order of 100 million degrees, as well as intense magnetic and electromagnetic fields. In meeting these challenges, the fusion community contributed significant advances in scientific instruments.

Instrumentation is an area where the synergism is strong and occurs rapidly. The major groups of plasma-related science regularly hold joint conferences to discuss advances made in measuring similar phenomena with essentially the same techniques.

SUPERCOMPUTING

Collaborative effort between the National Magnetic Fusion Computer Center and the Cray Research Company on the development of the Cray II computer helped to bring this computer into existence and demonstrated its value. The resulting computer sales have exceeded $200M. In addition, the fusion program developed a time-share operating system, used at many sites with Cray I and Cray II computers and adapted major engineering codes to supercomputers. Some of the systems have been licensed and incorporated into commercial products by several different companies. Adapted codes were quickly applied in commercial ventures; as an example, the fusion-adapted version of the NASTRAN code was employed extensively by Ford in the design o the TAURUS. The total commercial value of scientific computing developed in the magnetic fusion program has not been specifically quantified but is considered to be several hundred million dollars.

6

COMPUTATIONAL SCIENCE

Scientific Code Development

Techniques for solving the equations of fluid models of fusion plasmas have been used in such diverse disciplines as astrophysics, geophysics, solid-state physics, and high energy physics.

Numerical Techniques

On a very fundamental level, the computational effort in fusion research has built programs and techniques to evaluate basic mathematical constructs. The programs and techniques that have been developed are basic tools that can be used in other applications where the theoretical building blocks are similar.

Engineering Applications

In recent years, many practical developments in engineering, particularly electrical engineering, can be traced to initial work done by the fusion program in computational physics. The calculation of the magnetic field generated by complicated coils, the self-forces on the conductors, and the analysis of the stress by finite element methods were developed for routine calculations in the design and evaluation of magnetic fusion devices. These codes have been adapted by engineers working on other projects for magnetic design such as coal-fired MHD generators and both electromagnetic launch and levitation systems. In addition, the computational solution of the electromagnetic wave equation, developed in plasma heating studies, is being used in engineering applications ranging from antenna design to calculating radar cross sections.

TEDI Text Editor

The TEDI text editor was developed at Los Alamos and it is now adopted by the U.S. Fusion community, numerous industrial universities, and Cray Research, Inc., as their standard editor.

TECHNOLOGY AND KNOW-HOW ACQUIRED BY THE U.S. THROUGH INTERNATIONAL COLLABORATION ON FUSION

- Water-cooled coper grids for particle acceleration formed by copper deposition from Jülich (FRG).

- Fluorescent grid—electron beam system for measuring stellarator flux surfaces from Kharkov (USSR).

- Japanese and German scientists have supplied numerous new concepts and experimental results to incorporate into the Tritium Systems Test Assembly at Los Alamos.

- One of the most successful alternate concepts, presently under development at Los Alamos, the Reversed-Field Pinch was originally pioneered on the ZETA experiment at Culham Laboratories in Great Britain.

- The design of ZTH, presently under construction alt Los Alamos, benefitted greatly from the design of RFX at Padova, Italy. In particular, the ZTH magnetics concept is based on the RFX design.

- An 80-kev neutral particle beam for seeding the plasma with neutrals for diagnostic purposes was developed for PBX-M by Culham Laboratory/England.

- The development of PPPL's innovative low energy, high flux neutral beam facility for use in materials studies for NASA and the subsequent development of this source for charge-free etching was made possible, in part, by international cooperation on fusion. The basis of the neutralization method depends on the scattering properties of ions on biased metal surfaces. The theory and codes developed by physicists at Garching for plasma wall interactions were crucial in developing the idea behind the neutralization technique. The source of the plasma is a lower hybrid RF device which has also benefitted from developments of foreign collaboration.

- The smaller PF coils in TFTR were subcontracted to Brown Boveri & Company in Zurich, Switzerland and Mannheim, Germany to maintain the PF coil production schedule. This collaboration permitted a great deal of sharing of coil manufacturing technology between BBC and PPPL in areas such as epoxy impregnation techniques, conductor brazing techniques, and electrical insulation and testing techniques. BBC is one of the most experienced manufacturers of fusion magnets; similar industrial expertise in this area does not exist in the U.S. and, in fact, has been declining in recent years.

- PLT, TFTR, and the X-ray Laser Program ise(d) a dual detector spectrometer which was developed in Israel.

- The copper conductors in the large coils are subject to high shear stress. It is hard to get a good shear bond between epoxy and copper due to the rapid formation of an oxide layer. Ciba Geigy developed a primer called DZ-80 which is used on conductors of both the PF and TF coils for TFTR. This material was developed in Europe and was chosen as a result of extensive testing.

- Super conducting coils from the U.S., Japan, Switzerland, and Germany were fabricated and installed in a toroidal array at ORNL. This permitted a direct comparison of the superconducting technology state-of-the-art from several countries.
- Gyrotrons from USSR (Gorky) are becoming a U.S. industrial product at Varian Corporation.
- Neutral beams from USSR (Kurchatov Institute) have been used by U.S. labs, and now are being designed for ITER by Grumman Corporation.
- High-strength cryogenic steel from Japan and USSR has been developed. There is no comparable effort in the U.S.
- Radiation-tolerant insulators are being developed in Europe (Max-Planck Institute).

UNITED STATES HOUSE OF REPRESENTATIVES

SCIENCE, SPACE, AND TECHNOLOGY COMMITTEE

SUBCOMMITTEE ON ENERGY

APRIL 11, 1991

Written Comments By

Dr William R Ellis
Vice President, Advanced Systems Engineering Engineering
and Chief Scientist for Ebasco

Ebasco Services Incorporated
Two World Trade Center
New York, New York 10048
(212) 839-3398

I appreciate the opportunity to submit written comments to the Subcommittee about the U.S. fusion program on behalf of Ebasco Services Incorporated. Ebasco is a leader in the fields of energy, environment and infrastructure. Ebasco offers complete turnkey construction, as well as engineering, environmental and advanced technology services, and quality management systems to government, utility and private sector clients throughout the world.

Ebasco has been deeply involved in the fusion program for over 15 years. Ebasco was the industrial contractor for the Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory (PPPL). Ebasco also did Phase I design work for the Elmo Bumpy Torus Proof of Principle experiment (EBT-P) at the Oak Ridge National Laboratory (ORNL) and was a participant in the Mirror Advanced Reactor Study (MARS) for the Lawrence Livermore National Laboratory (LLNL). Ebasco was selected to handle the vacuum vessel, first wall, divertor, and remote maintenance components of the new Burning Plasma Experiment (BPX) at PPL; and, most recently, began work on two Inertial Fusion Energy (IFE) reactor designs for the Department of Energy (DOE). This broad base of fusion technology experience is unmatched by any other U.S. company.

I am writing to the Subcommittee to support the President's budget request in FY 1992 for both magnetic and inertial confinement fusion. The U.S. fusion program underwent an extensive review in 1990 by the Fusion Policy Advisory Committee (FPAC), established by Secretary Watkins, which made recommendations for significant changes in the technical, programmatic, and policy areas of the program. FPAC's recommendations have been largely incorporated into the National Energy Strategy (NES) document which was recently released by DOE, and in the fusion budget request for FY 1992. FPAC's primary recommendation was that the U.S. fusion program be restructured into an energy development program, as opposed to a research program, with two main thrusts: construction of the BPX as a national facility, to study the physics of burning plasmas and build the necessary U.S. industrial technology base; and participation in the International Thermonuclear Experimental Reactor (ITER) project, sponsored by the International Atomic Energy Agency (IAEA), which is now entering its engineering design phase.

Ebasco endorses the positions of the NES and FPAC with regard to the importance of fusion to this country and to the world. DOE's program strategy represents an important change in direction for fusion and a significant opportunity to make fusion into a real energy option. Ebasco supports this change wholeheartedly and urges strong support by the Congress to make

these plans a reality. Fusion is too important to the country's overall future energy needs to be allowed to languish or perish for lack of funding because of its long term nature. Budget growth will be necessary to allow a realistic fusion energy development effort. Ebasco supports the Administration's FY 1992 budget request for Magnetic Fusion Energy (MFE) as a reasonable starting point. Eventually, budgets which are double the present $300 M per year will be required.

Beyond supporting the President's budget request, there are two additional steps which the Congress could take to demonstrate support for fusion, which would not require any additional budget increases in FY 1992. The first is to designate BPX as a line item project in the budget. Project designation would permit the most effective use of BPX funds and show a serious commitment to BPX as the national flagship in fusion. The second would be to recommend that DOE reconsider their decision to permanently shut down the Advanced Toroidal Facility at Oak Ridge. The ATF, which only recently began producing data, is uniquely suited to investigate important toroidal physics and technology issues relevant to the mainline tokamaks, in particular, the issue of ultra long-pulses and steady-state operation. A technical review of the ATF with respect to its potential contributions would seem to be appropriate.

I am also writing to support the needs of the Inertial Confinement Fusion (ICF) program, which, as you know, is funded primarily through the DOE Defense Program budget. The ICF program was included in FPAC's review of fusion, and has been coordinated with the MFE program in DOE's National Energy Strategy. The ICF program is deserving of the Congress' support.

In summary, Ebasco congratulates the Subcommittee for its foresight and perseverance in supporting an energy resource of the future. I urge the Subcommittee to continue its support for fusion, by supporting the President's budget and facilitating the more focused program which has been embarked upon by the DOE, the fusion technical community, and the fusion technology industry. The full participation of industry throughout the development process is vital to its prospects for success.

I appreciate the opportunity to present these written comments in support of the fusion program, and would be pleased to provide additional information to the Subcommittee.

WRE:GF

APPENDIX III

Department of Energy
Washington, DC 20585
May 1, 1991

The Honorable Marilyn Lloyd
Chairman
Subcommittee on Energy
Committee on Science, Space, and Technology
U.S. House of Representatives
Washington, DC 20515

Dear Madam Chairman:

On March 13, 1991, Dr. James F. Decker, Acting Director, Office of Energy Research, accompanied by Dr. N. Anne Davies, Acting Associate Director, Office of Fusion Energy, testified before your subcommittee on the FY92 budget request for the Department of Energy's Fusion Energy Research Program.

Following the hearing, you submitted two written questions to supplement the record. Enclosed are the answers to those questions.

If we can be of further assistance to you or your staff, please contact our Congressional Hearing Coordinator, Barbara Campbell, on (202) 586-8238.

Sincerely,

Jacqueline Knox Brown
Assistant Secretary
Congressional and Intergovernmental Affairs

Enclosures

42-670 0 - 91 - 6

QUESTIONS FROM REPRESENTATIVE LLOYD

Question #1: We understand that the Department of Energy has recently been contacting officials in other countries with a view to obtaining funding for the BPX program. Could you elaborate on this international effort and can you give any specific dollar ($) amounts which you can realistically foresee as foreign contributions? What will be the Quid pro Quo that we will be required to make? Are we prepared to fund similar programs in other countries?

Answer: Within the framework of the U.S.-European Community, EC, fusion bilateral, the DOE has proposed to the EC and to the Italian government that discussions be opened regarding possible collaboration on the Burning Plasma Experiment, BPX. In response, they have suggested that the U.S. and EC undertake together a joint assessment of compact burning plasma devices, which we have accepted. The DOE is currently making arrangements for this assessment, in which each site would support its own participants, to begin in May 1991.

No dollar amounts have been identified for any possible collaboration, arising from the joint assessment, either by the U.S. or by the EC. Since negotiations for a possible collaboration have not yet begun, there has been no discussion of any quid pro quo. Likewise, there has been no discussion of funding similar programs in the EC.

The USSR had previously proposed providing power supply components for the Compact Ignition Tokamak project. We

understand that the Soviets are still interested in collaborating on BPX in the event the project is funded for construction and may be willing to offer a similar arrangement on BPX power supply components.

Question #2: **Concerning out year funding for the BPX and ITER, please provide your latest cost estimates for the U.S. for the EDA phase of ITER. Include separate estimates for a U.S. site and for a site overseas. Also, identify any construction costs included in either estimate.**

Answer: The ITER Council, the supervising body of the four International Thermonuclear Experimental Reactor, ITER, parties for the ITER Conceptual Design Activities, has estimated the cost for the ITER Engineering Design Activities, EDA, to $1.0 billion, FY 1989 dollars, which we have escalated to $1.2 billion in FY 1992 dollars. The agreement is currently being negotiated and it is intended that the four parties make equal, in-kind contributions to support this total. Therefore, the total U.S. cost would be $300 million over the period of the EDA, the great majority of which would be spent in the U.S. for ITER related research and development. The ITER EDA is planned to begin in FY 1991 and be completed in FY 1997. Our cost estimate for hosting the joint work site during EDA in the U.S. is approximately $32 million. Our cost estimate for sending U.S. participants to a joint work site at Garching, Germany, is approximately $24 million. No construction costs are included in these estimates.

Princeton University
Plasma Physics Laboratory

Office of the Director
James Forrestal Campus
P.O. Box 451, Princeton, N.J. 08543
609-243-3553
609-243-2749 (FAX)

APR 22 1991

April 16, 1991

The Honorable Marilyn Lloyd, Chairman
United States House of Representatives
Subcommittee on Energy
Committee on Science, Space, and Technology
Suite 2320 Rayburn House Office Building
Washington, DC 20515

Dear Mrs. Lloyd:

Thank you for giving me and other members of the fusion community the opportunity to testify before your subcommittee on the U.S Fusion Energy Program. I believe the well-organized hearing elicited some valuable information. All of us in the fusion program appreciate the help and guidance you have given us.

I am pleased to respond to the additional questions you have sent to me. My responses are attached to this page.

Sincerely,

Ron Davidson

Ronald C. Davidson
Director

Question 1.

Could you indicate what progress is being made at Princeton, or more generally in the U.S. Fusion Energy Program, on the important developmental area of reliable plasma control systems, in particular on the problem of minimizing uncontrolled plasma disruptions and plasma energy dumping to the containment vessel. Do you foresee that within a few more years of R&D effort this particular problem can be resolved?

Response 1.

One of the long-standing issues of tokamak research has been the effect of disruptions, which occur when the plasma column become unstable. In modern tokamaks the electrical current flowing in the plasma around the toroidal chamber is very energetic. If the plasma breaks out of the confining magnetic fields, it can hit the wall with vigorous force. Considerable progress has been made in the understanding of processes responsible for disruptions, and present-day experiments have been successful in developing regimes of plasma operation in which disruptions are largely avoided. Nonetheless, present and future tokamaks must be designed to withstand disruptions, which occur occasionally.

Based on experience from DIII-D at General Atomics and the Joint European Torus (JET), the planned operating point for the Burning Plasma Experiment (BPX) and the International Thermonuclear Experimental Reactor (ITER) with respect to plasma pressure, elongation, and toroidal current are expected to be relatively disruption-free. For example, at the BPX operating parameters, DIII-D experiences less than 1 percent disruptivity. Although some of the ITER operating regimes have somewhat higher levels of anticipated disruptivity, the device is designed with current profile controls that should reduce disruptivity. Research and development in the area of disruption characterization and control are very important elements for further emphasis in the U.S. and world fusion programs.

A number of innovative techniques for the control of precursor instabilities are being investigated on present experiments. Fine adjustments in the plasma heating and the current drive, combined with feedback control of non-axisymmetric fields, are likely to produce fewer and softer disruptions in future experiments than occur in present day machines, thereby easing further the engineering design requirements.

Question 2.

What steps does PPPL plan to undertake in the BPX program to increase industry participation in all phases of this program to expedite technology development and draw on industry's strengths?

Response 2.

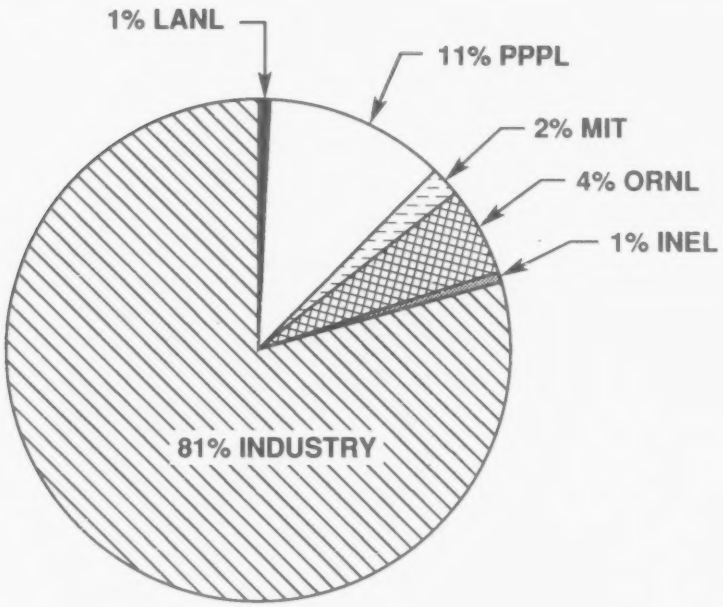
The BPX Project is committed to maximizing the role of industry in the design, R&D, and construction of the facility.

Industry is presently involved in BPX design and R&D. Ebasco and their subcontractors have full responsibility for the Vacuum Vessel Systems set of work packages (over $100M scope). Grumman Aerospace Corporation is responsible for Project design integration. The growing project R&D program is bringing an increased industrial involvement. Integrated over the total construction phase, contracts to industry will account for over 80% of Project expenditures. This is shown on the attached chart of the distribution of BPX costs.

The role of industry will increase as the Project makes the transition from conceptual design to final design and construction. In FY 1992 an Architect Engineering contract will be awarded for the design of $100M worth of new buildings. Industrial contracts will be awarded in late FY 1992 and early FY 1993 for the tokamak component prototypes. In FY 1994 and early FY 1995 most of the large construction and fabrication contracts will be awarded.

PPPL#91P0006

Industrial Participation in BPX



Private Sector Participation in Burning Plasma Experiment

Industrial contracts for the BPX Project will total approximately $5M for FY1991 and $12M for FY1992. Firms that have participated to date include:

Brush Wellman
EBASCO
General Atomics
Grumman Aerospace Corp.
McDonnell Douglas Astronautics Co.
Parsons Brinkerhoff
SPAR Aerospace Limited
Science Applications International Corp.
Stone and Webster

University/Laboratory Participation in Burning Plasma Experiment

Argonne National Laboratory
Hunter College
Idaho National Engineering Laboratory
Livermore National Laboratory
Los Alamos National Laboratory
Massachusetts Institute of Technology
New York University
Oak Ridge National Laboratory
Princeton Plasma Physics Laboratory
University of California, Los Angeles
University of Illinois
University of Wisconsin
Sandia National Laboratory

PLASMA FUSION CENTER

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS 02139

Ronald R. Parker, Director

telephone: (617) 253-5553
telefax: (617) 253-0570

April 22, 1991

Ms. Cheryl Faunce
Subcommittee on Energy
Committee on Science, Space and Technology
U.S. House of Representatives
Suite 2320, Rayburn House Office Building
Washington, DC 20515

Dear Ms. Faunce:

I am pleased to provide you with the enclosed response to the question for the record posed to me in Chairman Lloyd's April 2, 1991 letter.

Please let me know if I can provide any further information.

Sincerely,

Ronald R. Parker

Ronald R. Parker

Question for the Record
Dr. Ronald R. Parker
Plasma Fusion Center
Massachusetts Institute of Technology

In the current U.S. Fusion Energy program balance, do you believe that sufficient attention and resources are being devoted to research targeted to increasing the safety, environmental and economic attractiveness of future fusion power systems? If the emphasis is now inadequate, do you have views on what additional efforts should be initiated?

The steady decline of funding for the DOE fusion program over the last decade has caused a narrowing of the research effort. While there has been no official OFE policy which could be used to provide guidance on the structuring of the program during this time, the *defacto* policy has been to focus on confinement research, particularly that which could yield the most important near term gains. Thus, there has been little or no investment in future devices, nor high risk concepts, especially those which might have only a long term payoff.

A particularly glaring omission from OFE's program is a sustained, critical-mass effort on the development of materials which are critical for the safety and environmental attractiveness of fusion energy. While it might seem that the energy focus recommended for the program by FPAC might turn the situation around, in fact the opposite is likely to happen. This is so because the technology part of the program will mainly be required to support ITER, and the only technologies which can be used in ITER are those which exist, at least in primitive form, today. Thus, technology development which will be critically needed for a post-ITER device will probably be sacrificed in order to support ITER-relevant R & D.

I am a strong proponent of fencing a small fraction of the program's resources for development of advanced concepts and technologies. In the confinement area, efforts on disruption control, improved divertor designs and enhanced efficiency current drive methods need to be fostered. A particular technology which I believe should be stimulated is the development of low activation materials. Materials such as silicon carbide need to be developed, practical manufacturing methods must be found, and the materials must be tested and characterized for use in a fusion reactor. The *raison d'être* for fusion research is to provide a source of nuclear energy, with a fuel mass efficiency comparable to fission, but without fission's safety and waste disposal problems. Without the existence of low activation materials in hand, fusion's potential becomes largely empty rhetoric. Thus, I would urge OFE to put limited, but protected, resources into the systematic development of these materials.

Fusion Power Associates

Stephen O. Dean, President

APR 11 1991

April 8, 1991

The Honorable Marilyn Lloyd, Chairman
Subcommittee on Energy Research
and Development
B-374 Rayburn HOB
Washington D.C. 20515

Dear Marilyn:

Enclosed are my responses to the supplementary questions you sent to me for the hearing record of March 13 on fusion energy.

I appreciated the opportunity to testify.

Please let me know it I can be of further assistance.

Best regards,

Stephen O. Dean

Enclosures

2 Professional Drive, Suite 248 • Gaithersburg, Maryland 20879 • (301) 258-0546

ANSWERS TO QUESTIONS FOR THE RECORD

MARCH 13 HEARING ON FUSION ENERGY

DR. STEPHEN O. DEAN
FUSION POWER ASSOCIATES

1. If the budget were not sufficient for construction of the BPX, what would be the impact on the ITER program?

The most advanced facility in the U.S., the TFTR, was committed in the FY1976 budget, i.e., 15 years ago. During this same period the U.S. fusion budget has decreased, while the European and Japanese budgets have grown, so that the U.S. fusion program is now about one-half the size of the European program. If the U.S. budget cannot accommodate the BPX, then I think it is unlikely that the U.S. budget can accommodate a one-fourth contribution to the ITER. In this case ITER will not go forward as presently planned; most likely a European-only or Japanese-only fusion engineering test reactor will be built. If the U.S. is to be an equal partner in the international effort to develop fusion, it is essential that the U.S. have a strong national program that includes a new state-of-the-art tokamak facility.

2. What measures can be taken by the fusion energy program to increase meaningful participation by U.S. industry and thereby insure a long-term commitment on industry's part of this program?

The U.S. needs to have a balanced program that includes opportunities for industry to participate in the fusion program in several areas, including construction, research and development, and systems design and analysis. The most important single event that will command the interest of industry is the approval of a new major construction project in the U.S., like the BPX. Other factors that will draw industry into the fusion effort are opportunities to develop the technologies for ITER, opportunities to provide systems support, and opportunities to form partnerships with laboratories and universities to perform research and development. Many more competitive bidding opportunities should be made available by DOE in the fusion area.

Lawrence Livermore National Laboratory

April 11,. 1991

Marilyn Lloyd, Chairman
Subcommittee on Energy
Committee on Science, Space, and Technology
U. S. House of Representatives
Suite 2320, Rayburn House Office Building
Washington, DC 20515

Dear Chairman Lloyd:

I enclose the answer to the question to which you asked me to respond. I appreciate your continuing support for the Magnetic Fusion Energy Program, and interest in the ITER Project.

Yours sincerely,

Alexander J. Glass
U.S. ITER Home Team Leader

AJG91-108:mcr
Enclosure

Question for the Record
Dr. Alex Glass, Associate Director for Programs
Lawrence Livermore National Laboratory

1. On the International Thermonuclear Experimental Reactor (ITER) program, since the Europeans have a somewhat different view on the need or use of a blanket, could you give a figure for the additional construction cost involved if the capability to regenerate tritium were built into the ITER facility?

The ITER facility is designed to produce neutron fluences in the range of 1-3 MW-years/m^2. This neutron fluence is required if ITER is to meet the requirements of materials testing and to provide adequate neutron exposure to qualify blanket concepts for the Demonstration Reactor (DEMO). At this fluence level, a shielding blanket is required, whether or not it breeds tritium. Several breeder blanket concepts have been investigated. The preferred approach, for the United States point of view, uses beryllium metal as a neutron multiplier, and lithium oxide as the breeder material.

The estimated cost of developing the breeder blanket is $121 M. Of this total, $59 M would be required for blanket development, whether or not it is a breeder, and $62 M is required for specific development of the tritium-breeding capability. Thus the incremental cost of developing a breeding capability is about seven percent of the total long-term R&D cost for ITER.

The cost of construction of the breeder blanket is the cost of beryllium metal. At $600/kg, it is estimated that the cost of Be for the breeder will total $124 M. Again, this is a small fraction of the total capital cost of the ITER facility.

The current price of tritium purchased from the DOE is about $29 M/kg. At a fluence of 1 MW-year/m^2, ITER will consume 60 kg of tritium, at a cost of over $1.7 B. At the higher fluence of 3 MW-years/m^2, the tritium cost is over $5 B. There is clearly a strong financial incentive to include a tritium-breeding capability in ITER.

The ITER testing program is expected to extend over eight years. If the breeder blanket regenerates 80 percent of the tritium consumed, ITER will require an external tritium supply averaging 1.5 to 4.5 kg/year, at a cost of $44 M to $132 M annually, as part of the facilities operating cost.

04/11/91

Bechtel

50 Beale Street
San Francisco, CA 94105-1895
Mailing address: P.O. Box 193965
San Francisco, CA 94119-3965

April 10, 1991

The Honorable Marilyn Lloyd, Chairman
Subcommittee on Energy
U. S. House of Representatives
Committee on Science, Space, and Technology
Suite 2320 Rayburn House Office Building
Washington, DC 20515

Dear Madame Chairman:

The attached response to your question on industrial participation in fusion is offered for your consideration. I have taken the liberty of also including a White Paper on how industry could participate in the ITER. I hope these comments are useful.

Sincerely,

HK Forsen

Harold K. Forsen
Senior Vice President and Manager of
Research and Development

HKF:mc
Attachment

Question for the Record
Dr. Harold K. Forsen, Senior Vice President
and Manager of Research and Development
Bechtel Corporation

Question:

American industrial firms often appear to have a one or two year time horizon, in contrast to the longer-term investment orientation of Japanese companies. In that context, do you believe that the historical almost "hands-off" U. S. government policy is still appropriate or would you advocate a more aggressive federal role to promote technology transfer and private sector participation in the fusion program and do you have any specific suggestions for DOE or Congressional consideration or action along these lines?

Answer:

The short-term view of American industrial firms is driven by two factors in the case of fusion. First is their propensity to be short-term thinkers in general, but perhaps more importantly is the stagnation of nuclear power in the United States and the recognition that fusion is a nuclear power device. Second is the long development program fusion has suffered through. Industry, like Congress, has heard that fusion is just over the horizon and this ever receding goal has been hard to accept. For this reason, Congress's long-term view has been vital to the program.

There are perhaps two other issues that industry in America has had to contend with in fusion. One is that the budget has been insufficiently stable to permit initiative to industry to be sustained. The stop-start nature of industrial programs in fusion makes it hard to attract management attention to the opportunity.

Second is the real difference between the U.S. National Laboratory capability and those of Japan - including Japanese universities. In the States these Institutions have engineering design and fabrication capabilities which in a real sense competes with industry in that it allows them to perform work where industry would benefit. This would be technology transfer at its best since, as in Japan, the institution would be required to work closely with industry to get what they want, designed and built. Technology transfer through design and fabrication for National Laboratories will suffer so long as they have the capability to be independent of industry.

As a result of the above several issues in fusion, Congress could well take action to initiate a noncompetitive program to bring industry skills into the program such that a competitive industry can be assured later.

The attached paper describes how DOE could set up a program to perform efficient technology transfer in the design of ITER.

Harold K. Forsen

INDUSTRIAL PARTICIPATION IN ITER

Harold K. Forsen
Bechtel Corporation
San Francisco

FUSION POWER SYSTEMS - EVOLUTION

INTRODUCTION

The history of activity in the pursuit of fusion power has been developed by several authors and does not need to be repeated here. This paper deals with the opportunity provided by the movement of the magnetic fusion program towards a power system and in particular the opportunity that the International Thermonuclear Experimental Reactor (ITER) program provides for integrating the U.S. industrial base into this program.

Throughout the development of fusion power, "success" has too often been considered just a few more measurements, a few more experiments and a few more years away. This moving target has resulted in several serious problems for the program. Perhaps the worst is that American industry for the most part seems to have given up on fusion. This is in addition to the impatience with the very long-term and costly nature of the program sometimes manifest by Congress and the Administration. The result has been an inadequate constituency of support beyond the dedicated individuals and institutions already involved in fusion development.

Recent reviews by various advisory committees have all revealed that the fusion research program has made enormous progress; the scientific and technological developments, enhanced by international collaborations, have been outstanding. The important conclusion is that this progress has carried the program to the turning point from which it can begin to move toward its longer term role as an energy source. Clearly much remains to be accomplished, and the engineering database needed to design and license a fusion reactor is years off. Nonetheless, the international progress has brought the program to the point where an engineering test reactor (ETR) can be designed and built. Such a device would combine all of the physics issues of fusion power systems and provide a test bed for the engineering systems to understand the problems and test their performance in a fusion environment. This does not mean that all the engineering problems can be explored or solved in this device; many smaller scale test facilities will be required to accomplish this, but it will be the first integrated physics and engineering facility. Because of the experimental nature of this ETR and its test bed requirements for engineering systems, it will be expensive.

Fusion has always enjoyed unique and meaningful international collaboration, which is now being used as the basis for the design and implementation of the ITER. The principal parties to this collaboration are the United States, European Community, Japan, and the Soviet Union. Details of ITER are well documented elsewhere but the plan is to have the four parties perform both R & D and detailed design for the program over a five year period at a cost of roughly one billion dollars - shared equally. At the end of this period, a decision will be made on a possible collaboration to construct and operate ITER. The scale and goals of the project, requires that U. S. industries have a meaningful role.

NATIONAL LABORATORIES - UNIVERSITIES

The history of fusion shows that the national laboratories and universities have provided most of the science, technology and continuity needed for its development. U. S. industry participated early-on and in component or subsystem roles, but its involvement has not been nearly broad or continuous enough to begin to prepare it to take on its ultimate role as supplier. Constrained funding has inhibited a larger industrial role in recent years.

This is said with the idea of industry as a whole. There is one partial exception. General Atomics has been a continuous participant from before the program was declassified in 1958. They clearly could be prepared to move forward as an important industrial participant as the program progresses. However, they are alone in the United States and R & D funding by the DOE puts them in a unique position. This important and unique activity is not sufficient since much more industrial infrastructure must be involved if the U. S. does not wish to purchase fusion power systems from principally overseas vendors in the future.

During the past three years of ITER conceptual design work, essentially all U. S. participants in the design have come from national laboratories or universities. The central design group in Germany was made up of experts who could make the greatest contribution to the physics and engineering issues at hand. The experience of these people and their colleagues in the program is important to its ultimate success.

Industry brings a minority contribution to this effort and its broad participation has been appropriately limited. However, as we move toward the detailed design of an extremely complex piece of hardware, facilities and infrastructure, industry has much to offer - while at the same time learning those necessary details unique to fusion power systems. It is worth noting here that although the U. S. effort in the ITER conceptual design was important, it was less than one quarter of the four party effort.

Further, a significant amount of the engineering work in Japan and the E.C. was done by industries. The U. S. is already behind in bringing industry into a competitive position.

INDUSTRIAL ROLE

As the ITER prepares to undertake detailed design as an ETR, the many systems, health and safety issues, and plant design aspects become more important and with this expanded menu of tasks industry can and should contribute more to the effort. The issue here is how to take advanage of industries' experience while accepting the position that they do not have an adequate understanding of fusion to take a lead role in ITER during the impending engineering design phase.

The idea of using the ITER engineering design activity (EDA) to provide a technology transfer vehicle to industry is obvious. The question is how to implement this technology transfer in a manner which will bring American industry up to the levels already achieved by the Japanese and approach that of General Atomics. We must organize the activity so that our industries receive adequate input and can then provide larger and more significant output as the fusion program develops. Our ultimate objective should be to position American industry to compete for future contracts on ITER, and, more importantly, to begin the development of an infrastructure to build future fusion power plants.

Unlike the early development of fission power, the U. S. has not set up the equivalent of a Bettis Laboratory or Knowles Atomic Power Laboratory to carry out a key fusion mission and operated by the relevant industries. We now are faced with a situation where industry is in the wings of the program, showing at best a casual interest in fusion while it tries to get LWR fission power going again. Fusion can only play a futuristic R & D role in the industries' nuclear thinking. This then presents two problems: 1. How do we interest the appropriate industrial companies in participating in fusion, and 2. How do we open up the opportunities that ITER presents on an equitable basis.

Here it is both instructive and important to think about who would be the industrial suppliers of a fusion power economy. The real issue in thinking this through is who will be prepared to provide the system performance guarantees to the owner. Although many specifics cannot yet be known, it is reasonable to anticipate that the systems suppliers for fission power are the most likely candidates. It is also probable that within the U. S. the nuclear experience will prevail in that architect/engineer contractors take on the balance of plant and overall systems integration. Finally, components for the steam supply vendor and for the balance of plant equipment

vendor will be supplied by a broad industry, many of whom are doing these things now - both for fusion experiments and fission power systems.

Whatever plan is developed to undertake technology transfer and industrial input, it is anticipated that an equitable opportunity to qualified participants must be provided.

ITER PROGRAM

R & D ELEMENTS

Assuming that the ITER program proceeds as planned, there will be two closely coupled parallel activities of R & D and design. The R & D part will have a design effort too but it will be mostly characterized as component and subsystem design, development and testing. This effort can be procured pretty much as it has in the past and a whole series of industries already compete in and support this effort, largely through the national laboratory programs.

While there undoubtedly are opportunities to do the R & D elements differently and/or better, there is a precedent here and the experience gives guidance as to what can be done. Perhaps the greatest problem is in gaining large-scale component and subsystem experience on those parts of the ITER program where other team members have primary responsibility. This deserves serious consideration since U. S. industries must gain experience in all parts of the system. Others will have opinions on how to do this better.

CENTRAL DESIGN GROUP

The Central Design Group (CDG) will presumably be made up of many of the same individuals who previously performed the conceptual design. Here is where the national laboratory and university talent can make the greatest contribution. This CDG should set design specifications and criteria, coordinate the R & D elements, perform configuration management, and in general have overall scientific and technical responsibility for the program. Industry should assist the CDG by bringing professional assistance to the design integration and configuration control tasks.

Since this is a four party activity, the U. S. contingent to the CDG must provide input back to the U. S. on all elements of the program, not just those where the U. S. has prime responsibility. Here a plan has to be developed to determine the detailed work that will be performed as a parallel effort in those areas where the U.S. does not have prime responsibility. As we understand today, the overall ITER program is to be carried out in such a way that any of the four parties could independently complete the

design and construct the facility at the end of the design phase. This means an enormous amount of documentation must be developed (and verified in several languages).

DOMESTIC DESIGN CENTER

Beyond the CDG must be a domestic design center (DDC) effort dedicated to carrying out the assigned engineering design tasks and managing the aforementioned total design capability. This center should be a clearing house for R & D input from the CDG and the domestic R & D effort, both technology and physics, but its greatest role in terms of this paper is to manage the engineering design analysis and detailed design. This should be done on a 3-D CAD system internationally compatible and transferable electronically to the CDG and various possible industrial sites. An important task of the CDG is to assure compatibility of designs from the four DDCs internationally, the sharing of these designs and full documentation.

Having set up a DDC, one must ask what role the national laboratories should play in this center versus that of industry. Here, unlike the core of the CDG, it can be argued that the role of industry should be quite significant. A national laboratory can provide the required continuity and oversight function; however, industry should not only provide R & D component development support but also execute the engineering design management using the vehicle of an industrial consortium.

While the cost of this program will be more than 25% of the full cost, it does not have to be 50%. There does not seem to be a less expensive way to get the full technology developed and transferred to those who can make use of it in the future. Some cost sharing by industry can be expected, but not very much because the payoff remains uncertain and many years into the future. Selection criteria among interested industries may be difficult and will be addressed in the next section.

INDUSTRIAL CONSORTIUM

Given the need and opportunity for industry to participate in ITER, principally through the DDC, and having specified to some extent who industry is, one must then think through how industrial participation is to be accomplished. The model proposed here is a consortium of interested industries representing principally the steam supply vendors, the architect/engineers and perhaps owner/operators. A consortium leader is competitively selected by the DOE with selection criteria based on the winner's ability to recruit, manage and offer reasonable independence from interested parties while being responsible to the DDC for the original detailed design assignment.

One of the key assignments, to which such a consortium should bring its experience and professional skills is the management of the engineering design. An organization which plays to the strengths and long term interests of all institutions is suggested in Figure 1. The Department of Energy, through its ITER Management Office, would have overall responsibility for program direction and funding. The DDC, presumably run by Livermore, would develop with the CDG, details of the technical tasks to be performed by the United States. The DDC would then have management authority over the three key functions of Technology R & D Management, Physics Management, and Engineering Management. As previously discussed, precedents exist for the management of the technology R & D and here the national naboratories should take lead roles - while keeping in mind that the purpose is to qualify United States component and subsystems suppliers to the extent possible. Physics R & D, conceptual design and theoretical studies should of course be managed by a national laboratory and most participation would come from already existing programs in confinement and theory. The industrial consortium would carry out the Engineering Management. In addition to configuration control and documentation, it would oversee the distribution and coordination of the specific design tasks amongst the most qualified component and system suppliers and the national laboratories.

It is anticipated that consortium members would participate after a leader is selected and that the participation would be on a reimbursable basis. As stated earlier, selection criteria for members could be on the quality and experience of their proposed staff. On the other hand, consideration could also be given to members' willingness to forego fee, relocation costs or other financial incentives. What must not be allowed is for one vendor to completely dominate the participation. For this reason some criteria must be developed based on size, history, and/or current nuclear activities. These criteria are key here because fusion in fact is a nuclear reactor. The body of individual knowledge for electric power production in the fission area will be important for fusion and for the possible purchase of fusion nuclear electric power.

Suppliers of hardware components and subsystems (such as those the aerospace companies have been providing) may wish to become nuclear fusion electric power plant suppliers. This is possible and may be encouraged but they bring considerably less to the party for nuclear system integration than the historical steam supply vendors.

Perhaps there will be no major problem in setting participation criteria limits in the several areas needed. For this to be a technology transfer opportunity, there must be roles for teams of people from appropriate industries. Having one or two people for literally hundreds of interested parties will probably not work. The planning and thinking needed to carry this out must parallel the manpower demand requirements for the DDC. If the CDG is kept small, as suggested, there will be a need for 50-100

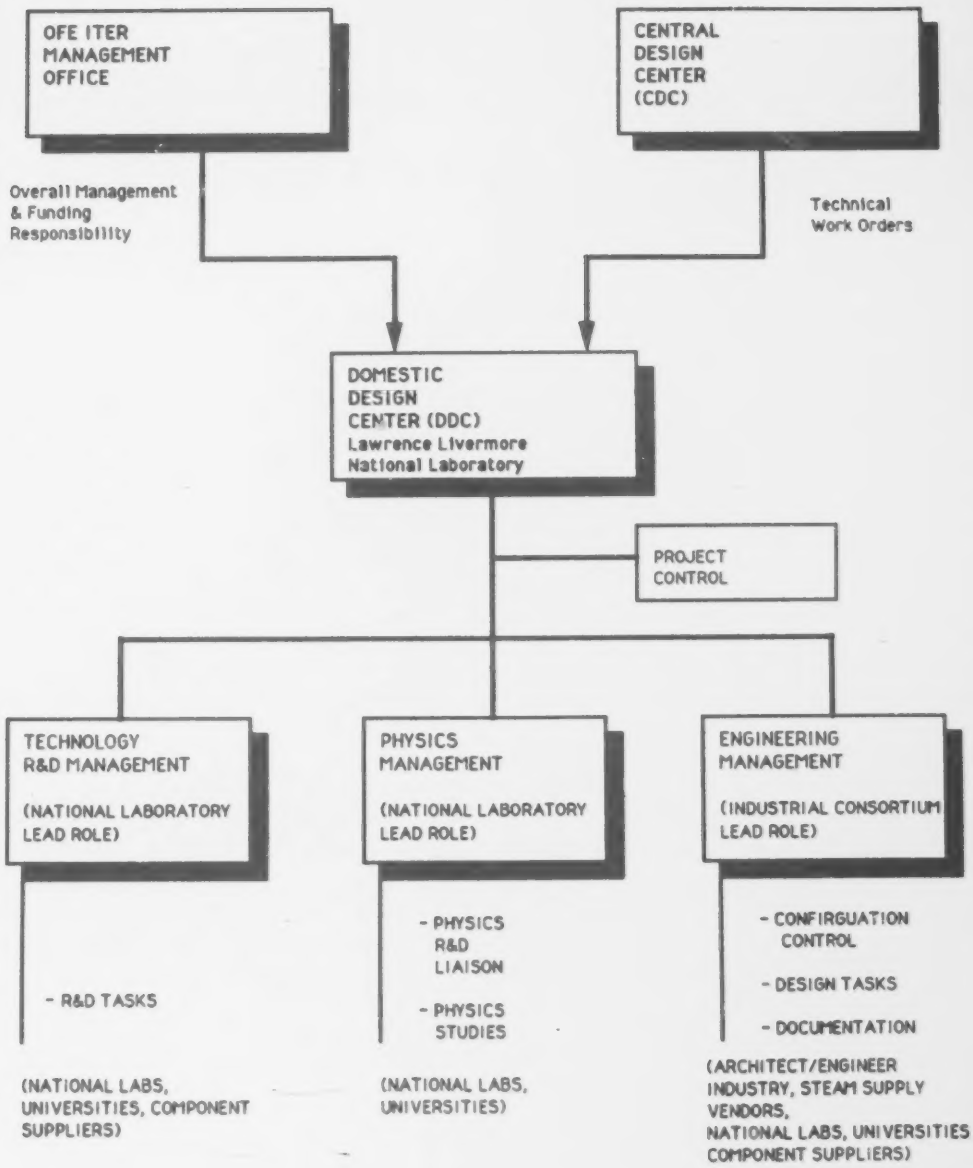
people at the DDC for Engineering Management - this is a real opportunity.

Given the work breakdown structure, it should be possible to have competitive designs outside the DDC for such nonnuclear components as magnets, beam sources (assuming still required), power systems, vacuum subsystems, and so on. This permits a competitive market to develop outside the steam supply vendors and would ultimately present them with viable make-or-buy opportunities.

CONCLUSION

The opportunity for U.S. industry to begin to take on an important leadership role in fusion power will be at hand in the next year or two with the detailed engineering effort for the ITER engineering design activity (EDA). Presented above is the skeleton of one way in which this can be accomplished. This paper is provided with the idea that we need to get on with the program and a key element of this will be industries' understanding of fusion - both as supplier and owner. As an ETR, ITER is an essential milestone on the road to fusion development. The follow-on engineering tests and data base development will assuredly be the key to whether a commercial demonstration in the United States can ever follow.

FIGURE 1
UNITED STATES ITER ORGANIZATION



Lawrence Berkeley Laboratory
1 Cyclotron Road Berkeley, California 94720
(415) 486-4000 • FTS 451-4000

April 15, 1991

Marilyn Lloyd, Chairman
Subcommittee on Energy
B-374 Rayburn House Office Building
Washington, D.C. 20515

Dear Chairman Lloyd:

Thank you for the opportunity to respond to your question of April 2. Unfortunately I was away from my office and didn't receive your letter until April 11. My response is enclosed. I hope it isn't too late.

Sincerely,

Roger O. Bangerter

ROB:dcm

enclosure

Question for the Record
Dr. Roger Bangerter, Group Leader
Heavy Ion Fusion Accelerator Research Division
Lawrence Berkeley Laboratory

1. *Could you give your view on whether the time is ripe now for more participation, by university faculty and graduate students in the civilian inertial confinement fusion program, or is it a bit too early? If appropriate, do you have suggestions for more substantial involvement by the academic sphere in aspects such as on material science issues and conceptual reactor studies especially as the ICF program moves forward?*

The time is certainly ripe for more participation by university faculty and graduate studies in the civilian inertial confinement fusion program. There is already some university participation. We currently have four graduate students working on accelerators for heavy ion fusion--three from the University of California at Davis and one from MIT. In addition, Prof. Virgil Schrock of the Nuclear Engineering Department at the University of California at Berkeley has three graduate students working on inertial fusion reactor issues, and Prof. Martin Reiser of the University of Maryland in working with students in fields relevant to heavy ion fusion. There is also university involvement in the two ongoing inertial fusion reactor studies sponsored by the Office of Fusion Energy. Finally, several of us are now presenting a series of lectures on inertial fusion at Princeton University. I am strongly in favor of the university involvement. I believe that it is important to train more students in inertial fusion.

In the past classification has been a barrier for some university faculty; however, classification barriers appear to be falling rapidly. I believe that interest exists at the universities and that we will have ample involvement if funding is available. In my opinion, even the lower of the two budget levels recommended for inertial fusion energy by the Fusion Policy Advisory Committee could allow significantly expanded university involvement. However, if the budget falls appreciably below this lower recommendation, it would become difficult to support either the ongoing industrial studies or increased university involvement.

GENERAL ATOMICS

April 19, 1991

The Honorable Marilyn Lloyd
Chairman, Subcommittee on Energy
Committee on Science, Space, and Technology
U.S. House of Representatives
Suite 2320 Rayburn House Office Building
Washington, D.C. 20515

Dear Madam Chairman:

It was an honor to have the opportunity to testify in front of your committee and express my opinions on the directions of the Magnetic Fusion Energy program. In particular, I want to again thank you and your committee for your long-standing support of the U.S. Magnetic Fusion Program

You have asked if there are any paradigms that I might suggest which could serve as a useful framework for the team approach with the private sector in a leadership role as I had mentioned in my written and oral testimony. I cannot think of any program that presently is under the auspices of the Department of Energy. There are numerous programs where the Department of Energy has U.S. industry playing a role, but it tends to be in support of national lab programs, such as AVLIS, which is being developed at Lawrence Livermore National Laboratory.

There are several examples where the Department of Defense has requested that industry play a lead role with national labs providing support to the lead industrial member. We at General Atomics have had explicit experience with one such a program, the ground–based Free Electron Laser, sponsored by the Army. The initial research was conducted at Livermore and Los Alamos National Laboratories. However, the design, engineering, construction, and operation of a large ground–based Free Electron Laser was to be awarded to an industrially–led team where the national labs, Livermore and Los Alamos, were to play a sub–contract role to the industrial lead. GA was a member of the TRW, GA, LLNL team. In the early research phase the industry team members worked with the national labs and acquired know–how and expertise in the area of Free Electron Lasers. In the second phase, the national labs were to support the industry through performing industry–directed R&D on problems that would have to be resolved to successfully complete the engineering and construct the facility.

We know from first–hand experience that Japanese industries generally take the lead role in Japan. The major national laboratories play a support role by providing some of the testing and research that is in support of the engineering design and the construction that has been contracted to the Japanese industry. Such a system could be very successful in the U.S.

3550 GENERAL ATOMICS COURT, SAN DIEGO, CA 92121-1194 P.O. BOX 85608, SAN DIEGO, CA 92138-5608 (619) 455-3000

We have reason to believe that the Department of Energy is considering such a policy and is prepared to make the transition to industry, national lab, university teams led by the industrial partner. Attached please find a letter from the Department of Energy to members of the Magnetic Fusion Energy community. As indicated in the letter, it is the Department's desire to begin forming teams and to foster closer working relationships between industries, national labs, and universities. Although the guidelines are not as explicit, nor as aggressive as we would like, we do believe it is a step in the right direction. Aggressive implementation of such a policy beginning with the fiscal 1992 budget will certainly mark a transition from the way in which engineering R&D has been performed in the past. If fully implemented, I believe the U.S. will be in a strong position to compete for ITER design and R&D activities while strengthening our industrial skills for the benefit of our long–term national fusion program.

If you require any further clarification, I will be happy to respond in writing, or I could come to Washington. We would also be honored if you could visit us at General Atomics to see first–hand our work in support of the U.S. Fusion Program.

Sincerely,

David O. Overskei
Senior Vice President
Fusion Group

DO:ms

cc: Ms. Kathryne Thorpe

GUIDELINES FOR U.S. INDUSTRIAL PARTICIPATION IN THE ITER PROGRAM

The Secretary of Energy's Fusion Policy Advisory Committee recently recommended that "Both MFE and IFE should increase industrial participation to permit an orderly transition to an energy program with strong emphasis on technology development...The sensitive and difficult process of transferring the technology should begin now...Also, an opportunity exists for industry to play a significant role in the U.S. Engineering Design Activities team in the International Thermonuclear Experimental Reactor project." Secretary of Energy Notice SEN-30-91, Setting the Course for Technology Transfer at the Department of Energy, dated January 23, 1991, states "Because U.S. competitiveness in international markets is seriously challenged, I feel that it is important to move as quickly as possible to expand and enhance DOE's cooperative work with industry." This notice refers to legislation that provides a basis for and encourages entering into Cooperative Research and Development Agreements (CRADAs) to more efficiently effect technology transfer and cooperative work between national laboratories and industry.

The Department of Energy intends to continue to support an on-going fusion program in the national laboratories and universities which will serve as the core for technology transfer and maintaining long-term U.S. research capability in fusion. The degree of laboratory and university involvement in fusion, however, will change with time as fusion development progresses through the technology and component development stage. Since the purpose of the ITER activity is to demonstrate the scientific and technological feasibility of fusion to provide commercial power, the U. S. intends that its industry have a significant role in the Engineering Design Activities (EDA) of the ITER program.

The following guidelines should apply during the term of the ITER EDA.

- The U.S. Home Team should establish contracts with industrial firms to participate in technology development in the major technology areas. The firms selected would work with the existing fusion research programs in national laboratories and universities to form teams to perform ITER-related research and development tasks.

- Component development of scalable models for the major R&D tasks assigned to the U.S. should be contracted to industry wherever practicable. The industrial contractors should be asked to work with the existing fusion research programs in the national laboratories and universities to establish their respective responsibilities for such component development. Having industry take the lead in the collaborative effort leading to design and development of scalable models would maximize the transfer of technology to the private sector.

- Where national laboratories have unique facilities necessary for component development and/or testing, these facilities will be made available to industry for ITER-related testing and other purposes.

- Design responsibilities will be assigned to laboratory, university, or industrial personnel as dictated by the availability of expertise. To the extent possible, industrial firms should participate in the areas where they have been selected to perform the related technology development tasks.

- Every effort will be made to ensure that U.S. industrial firms that have shown a strong interest in participating are provided information on the ITER design and R&D work. These efforts will include distribution of reports and the conduct of semi-annual workshops where the progress of the design and R&D effort are discussed. In addition, short and long-term assignments of industrial personnel to the Home and Central Design Teams will be made available to work in areas of particular interest such as systems integration, configuration management, and engineering design management. These will be on a cost-competitive and cost-sharing basis.

- Industry will be funded to evaluate the application of U.S.-specific environmental, safety, and health regulations to the ITER project. The goal is to ensure that all ITER designs are consistent with or can be modified, without undo effort, to be consistent with these regulations.

- Industrial participants in ITER will be selected through competitive procurement.

○